Welcome to Workshop at HKCU , Concepts of Ancst; Outcomes of recent wksp (3)in India .Future plans

Julian Hunt

- Malaysian Commonwealth Studies Centre
- Univ of Cambridge, Trinity College ,
- Univ Coll London
- CERC Ltd ; co-chair ANCST; House of Lords UK

2nd ANCST Workshop on
"Atmosphere-ocean interactions in the Indo-Pacific basin and their impact on Asian climate”
23-24 November 2014,
Indian Institute of Science
Bengaluru, India

Indian Institute of Science
Bengaluru, India

Asian Network on Climate
Science and Technology (ANCST)

Prof Bhat and Prof Srinivasan at IISC and Divecca Centre , on behalf of ANCST

Steering Cttee :J.Pereira, J.Chan,J.Srinivasan

Participants; India,Japan, Sri Lanka. Vietnam, Malaysia , S’pore, UK ; Regrets . Li Lixao,(China) Y Tsai (Taiwan)

ANCST Concepts (www.ancst.org)

- Network for CST (Climate science and technology) researchers in Asia; via workshops , test cases/data bases

collaborative research projects; internet; new media (?);

- Focus on Asian aspects- eg extremes, large urban effects ;hazards/impacts; data communication;** policy research in Asian context;** -note IPCC 2014

  meetings with decision makers …)

- Work with existing regional/international initiatives? Eg ASEAN, IPCC, APEC, Asian air pollution…
- Involvement with non-research organisations?

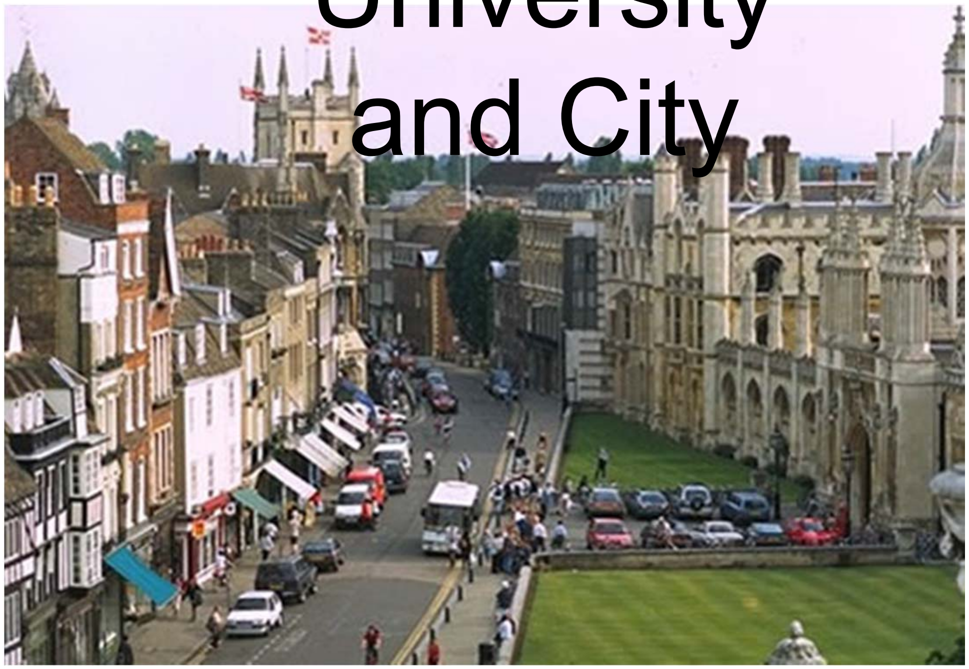
(eg private sector; government etc)-

as in Ercoftac (Euro network),

with a fee and perhaps a special ‘applications forum’?

Greetings from Cambridge University and City

MAINLY PEDESTRIAN
-NO THROUGH ROUTE!
-CYCLISTS



King's College
-famous for Chinese Poet

and scientist L.F.Richards on

Malaysian Cambridge Commonwealth Studies Centre

(sub office on Kings parade)

Cambridge Malaysian Education and Development Trust

(CERC Ltd founded in 1986 – environmental research collaboration with University of Cambridge)

Dutch navigators—'The land beneath the wind' 17 C !

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Prof John Pyle –
Chemistry ,Cambridge

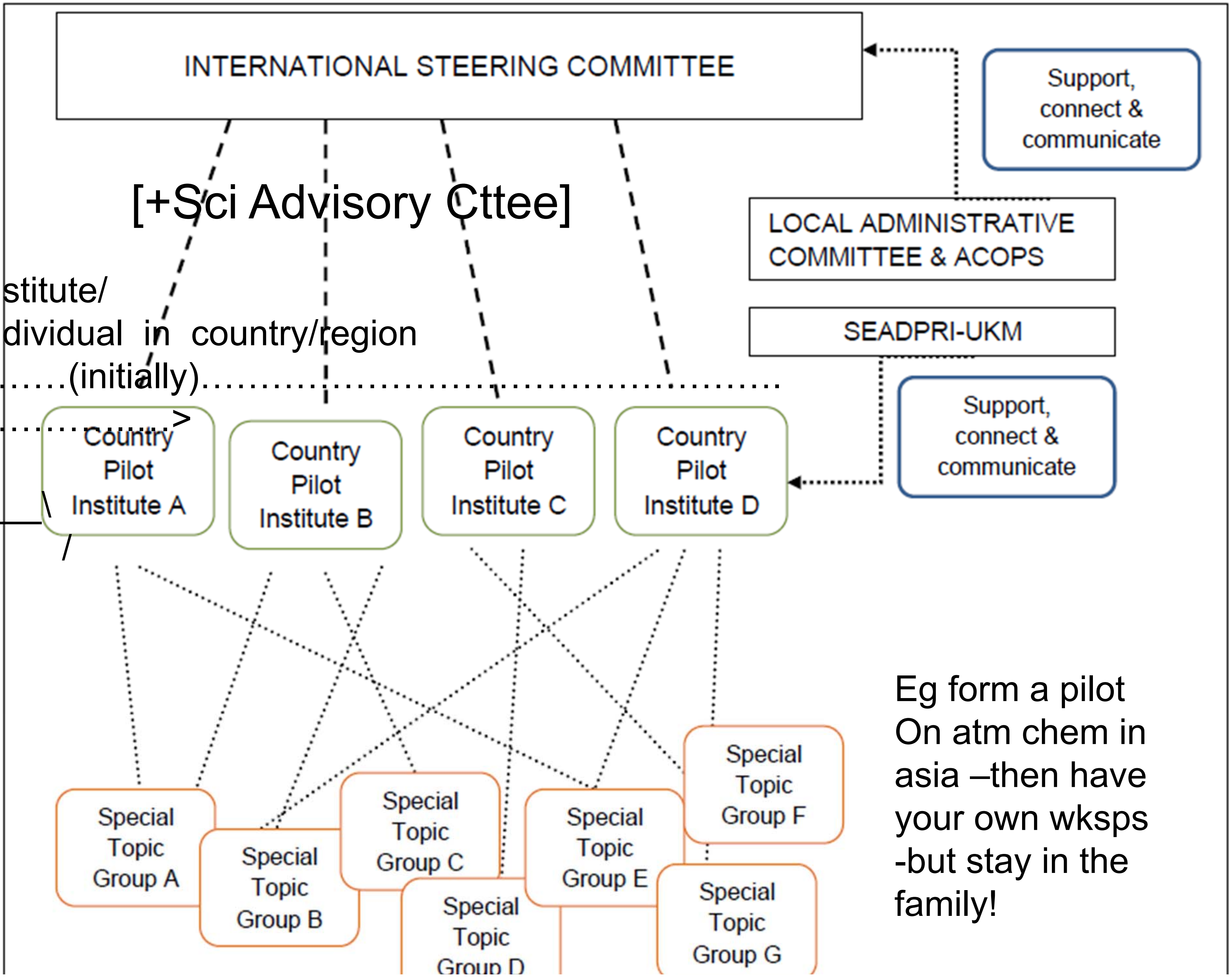
First two sites in Borneo during OP3 -halo carbon measurements

Special features of Equatorial Atm Chemistry

○ permanent
● mobile
⬭ cruise

(c)2007 ESRI, NGS, AND

New sites added, including Bachok in peninsular Malaysia



INTERNATIONAL STEERING COMMITTEE

[+Sci Advisory Cttee]

Support, connect & communicate

LOCAL ADMINISTRATIVE COMMITTEE & ACOPS

SEADPRI-UKM

Support, connect & communicate

Institute/
Individual in country/region A……(initially)…………………………………………
…………………>
|
|____\
/

Country Pilot Institute A

Country Pilot Institute B

Country Pilot Institute C

Country Pilot Institute D

Special Topic Group A

Special Topic Group B

Special Topic Group C

Special Topic Group D

Special Topic Group E

Special Topic Group F

Special Topic Group G

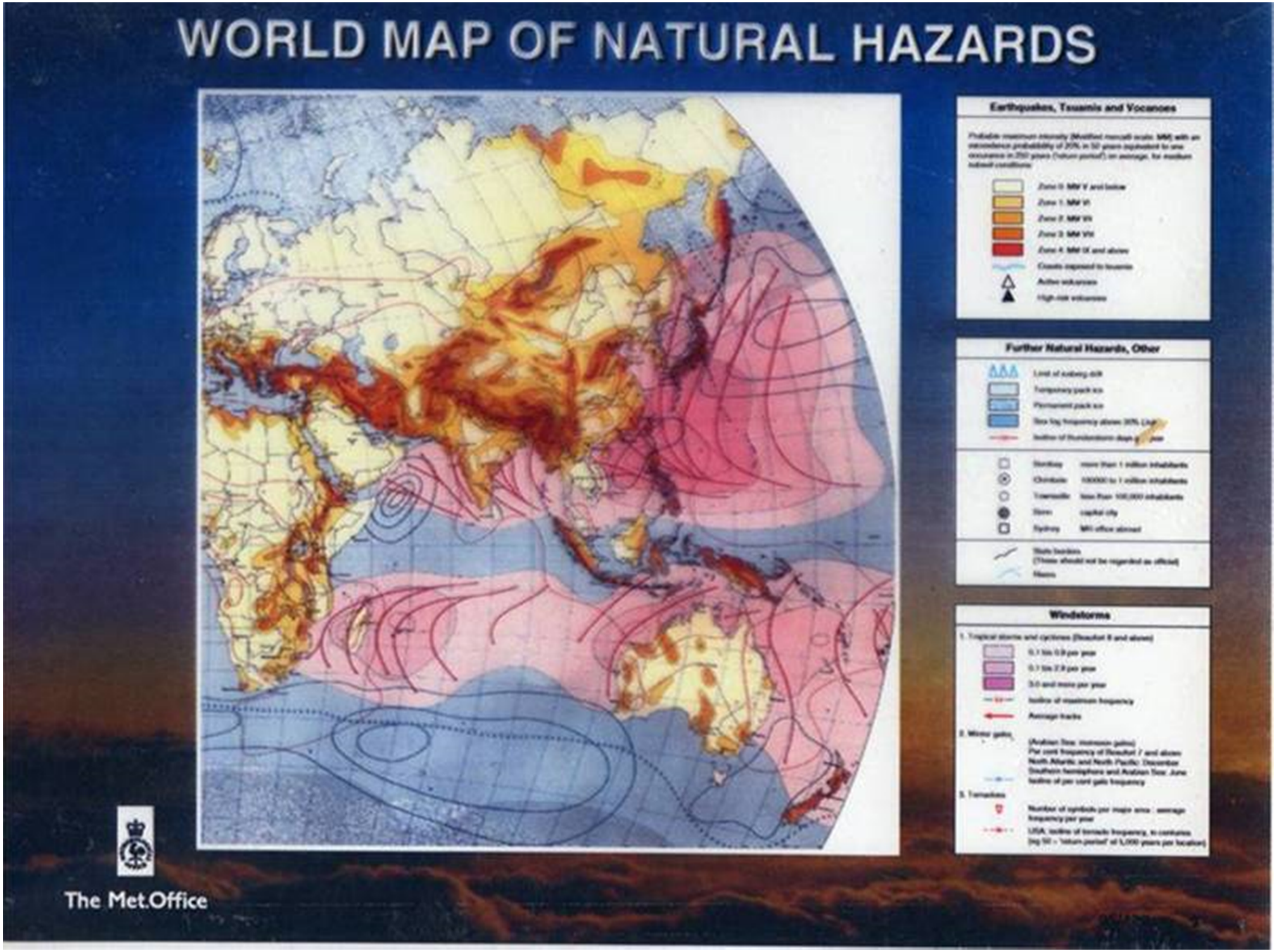
Eg form a pilot
On atm chem in
asia –then have
your own wksps
-but stay in the
family!

Proposed Organisation of the Asian Network on Climate Science and Technology (ANCST)---cf www.ERCOFTAC .org (1988) – data bases, test cases ,guide

Future developments

**Discussions about Ancst and future plans +new Water network

- Wksp 4 –Asian Urban Environments-Beijing July 2015 (China pub)
- Wksp 5 Disaster Resilience (APN)
- Wksp 6 climate and mountains(CAS) Wksp 7Change &Green Technology



Critical characteristics of ocean-atmosphere dynamics in Asia

MAIN RESULTS OF WKSP 3

(REPORTED IN CURRENT SCIIENCE , VOL 108, 10, APRIL 2015)-
GOOD WAY TO PUBLISH FAST ANCST MEETINGS

(1)RECENT DATA IN INDIAN OCEAN, AND OCEAN /ATM COMP MODELLING –EG CORDEX

- -> NEW ASPECTS OF SEASONAL , MULTI-YEAR CLIMATIC OSCILLATIONS AND REGIONAL COUPLING (eg S'PORE)

- ; INDIAN OCEAN DIPOLE (IOD) , EQUATORIAL INDIAN OCEAN OCEAN (EQUINOO) OSCILLATION INTERACTING WITH
- ENSO, MONSOONS, MJO

- …EUINOO PLUS ENSO AFFECTS INDIAN DROUGHT YEARS; ANTARCTIC, COLD SURGES…

- ENSO + MJO EXTREME RAINFALL IN VIETNAM;

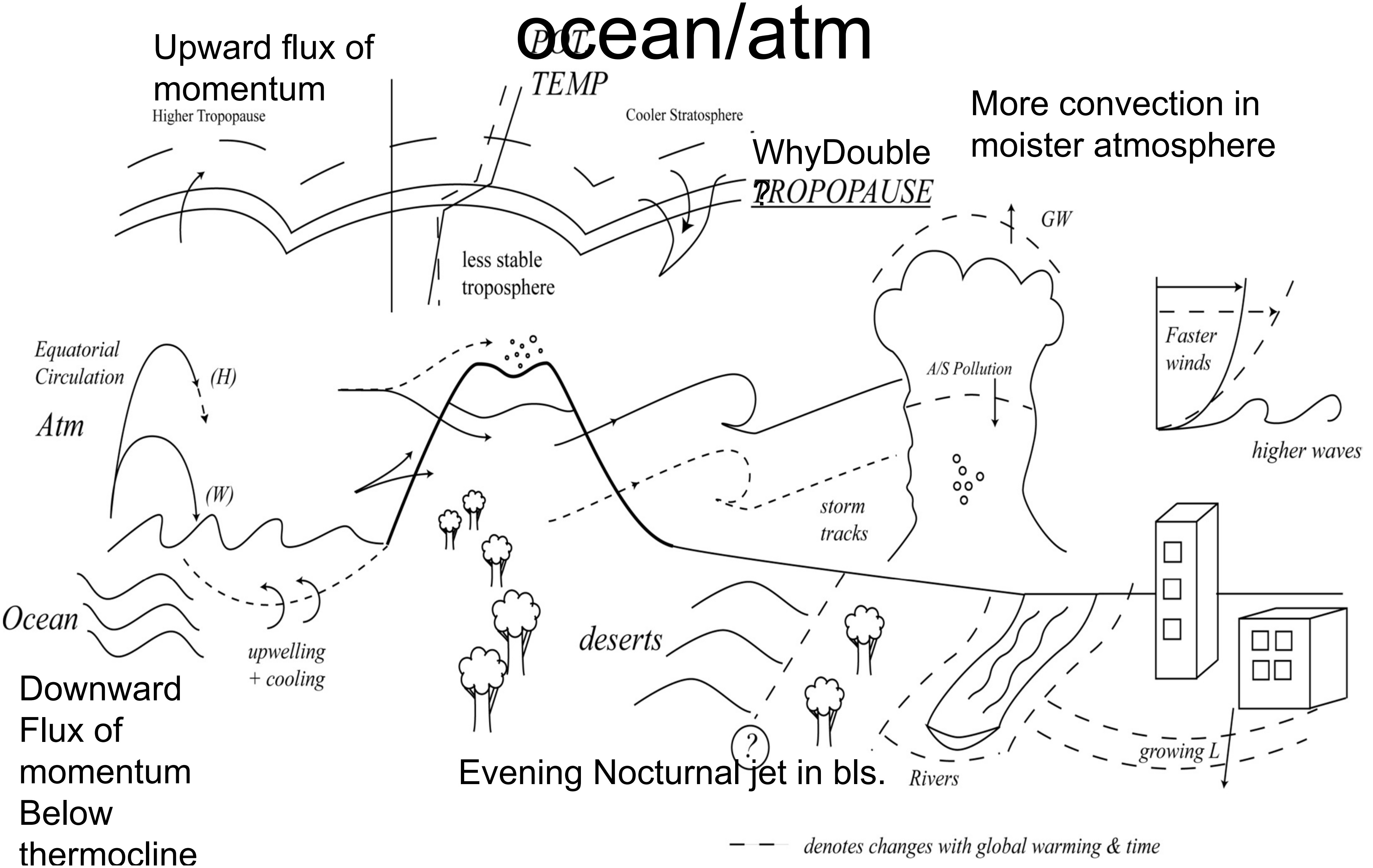
- (2) ABL+ OBL , AND INVERSIONS -> VARIATION OF MONSOONS ON E, W OF INDIA, RESPONSE TO TC , OCEAN FRONTS, UPWELLING , VERTICAL WAVE TURB COUPLING ; TC TURBULENCE ON MET TOWERS I

Turbulence & waves,below /above stratific'n & turb shear layers

- J.Hunt ,
- UCL , Cambridge UK.

- M.Moustaoui, A.Mahalov
- ASU
- Qu. Critical gfd flows where turb shear layers induce internal waves in strat layers. –but what is interface structure(s)? And how much momentum is transferred ?

some key questions for climate modelling about stratified layers in ocean/atm



Upward flux of momentum

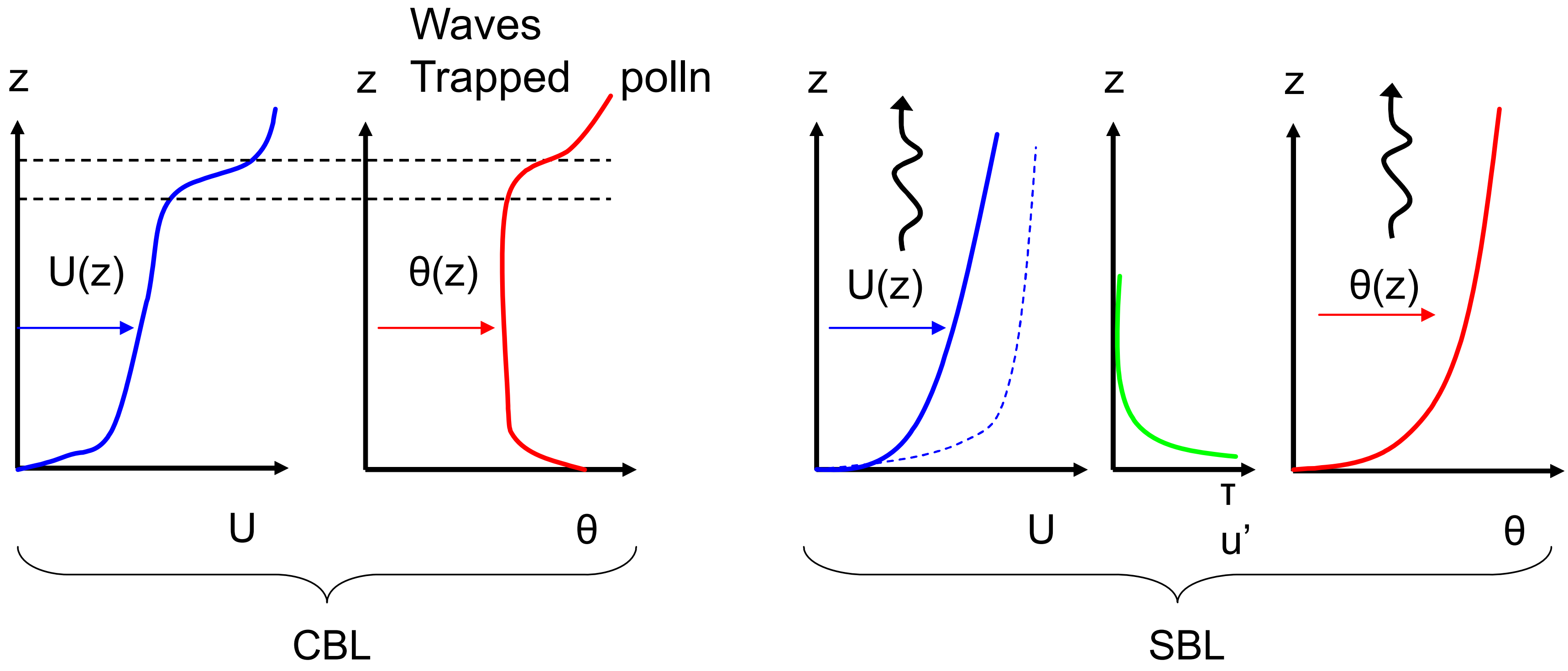
WhyDouble ?

More convection in moister atmosphere

Downward Flux of momentum Below thermocline

Evening Nocturnal jet in bls.

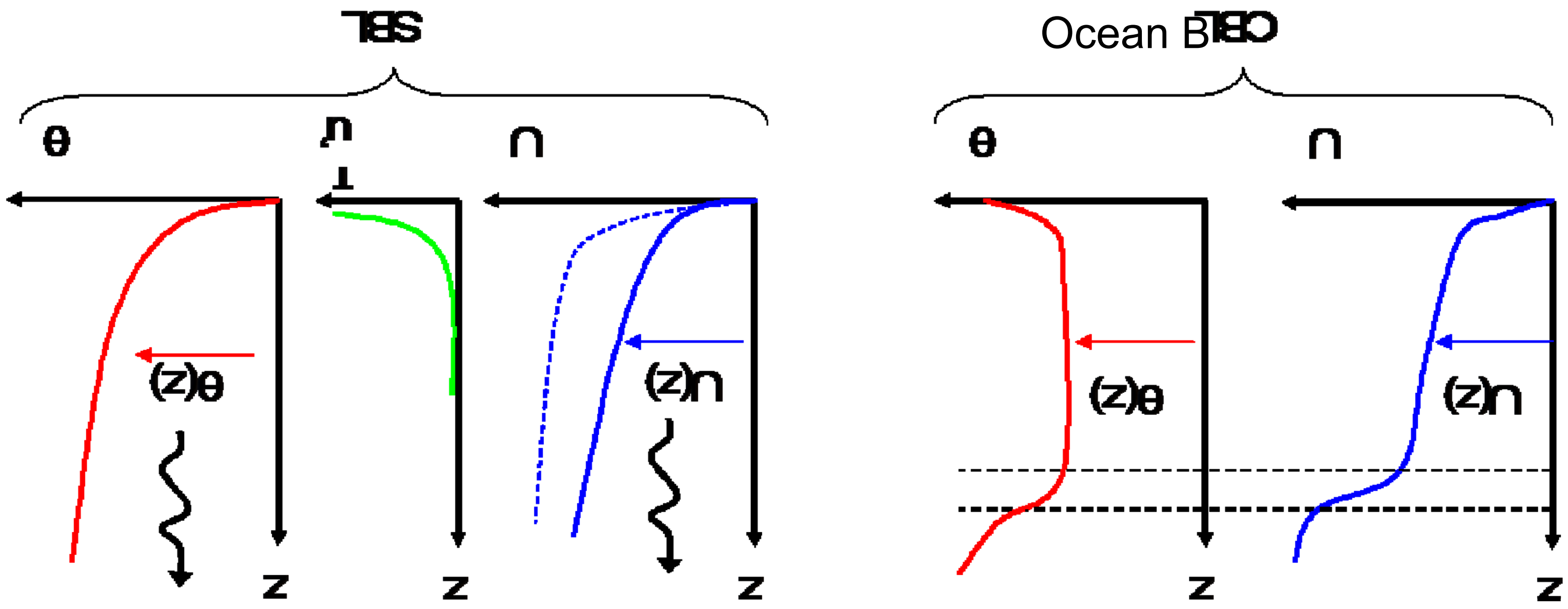
Boundary layers with stably stratified inversion layers



ATM BL –TURB SHEAR LAYER BELOW Zi ; STABLE REGION ABOVE Zi-DRIVEN BY PRESSURE FIELD –BUT AFFECTED BY WAVES-IN STRATOSPHERE.---ALSO AVALANCHES

OCEAN ML-TURB SHEAR LAYER ABOVE Zi; STABLE REGION BELOW Zi;DRIVEN BY INTERNAL WAVES FROM SHEAR LAYER(NOT IN GCM ?!)

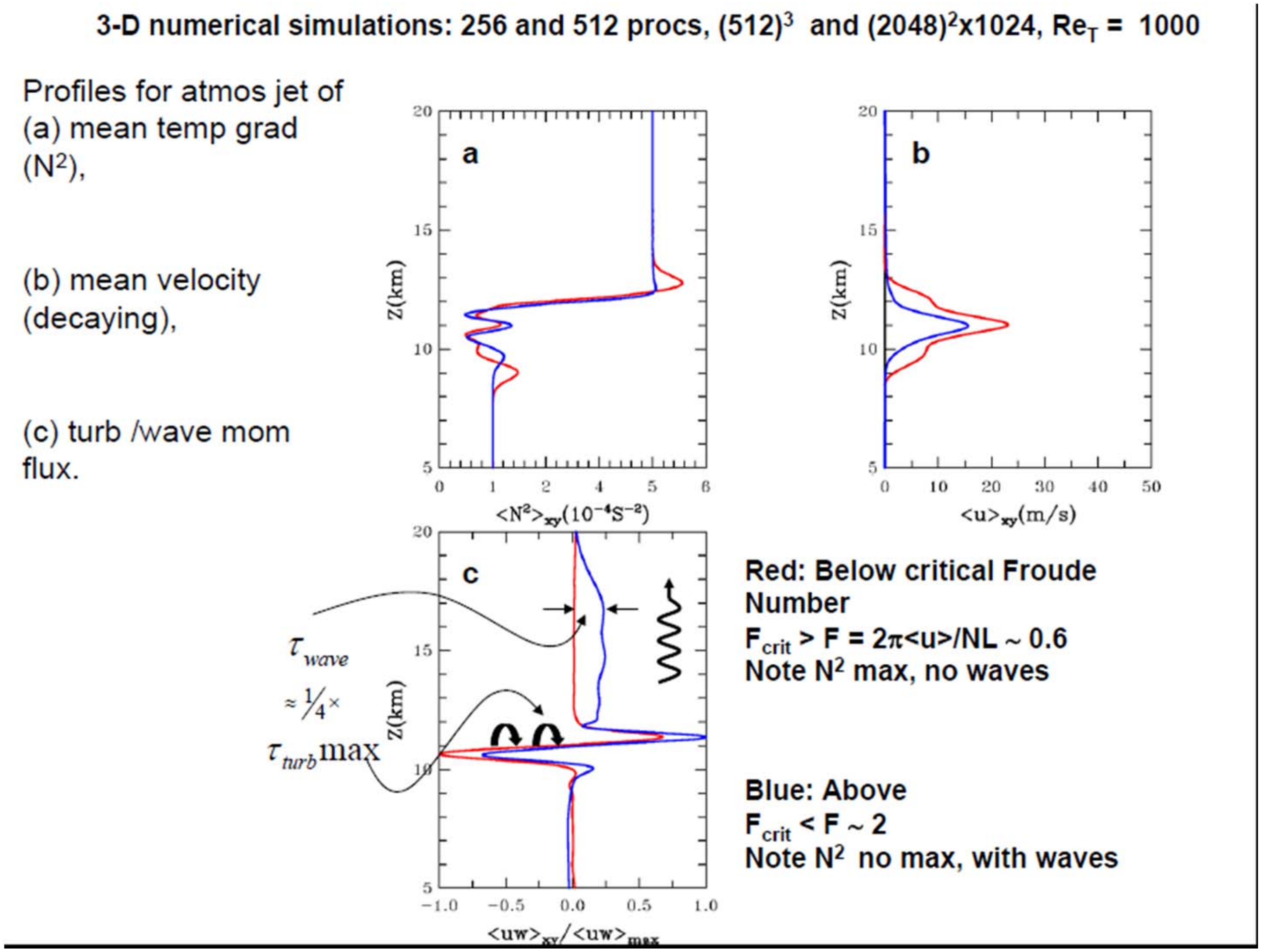
Strat Ocean Boundary layers without and with inversion layers



OCEAN ML- with strong strat below –waves

TURB SHEAR LAYER ABOVE Zi; STABLE REGION BELOW Zi;DRIVEN BY INTERNAL WAVES FROM SHEAR LAYER(NOT IN GCM ?!)

Jet below stratified layer -3D numerical simulations by M M



3-D numerical simulations: 256 and 512 procs, $(512)^3$ and $(2048)^2$x1024, Re_T = 1000

Profiles for atmos jet of
(a) mean temp grad (N^2),

(b) mean velocity (decaying),

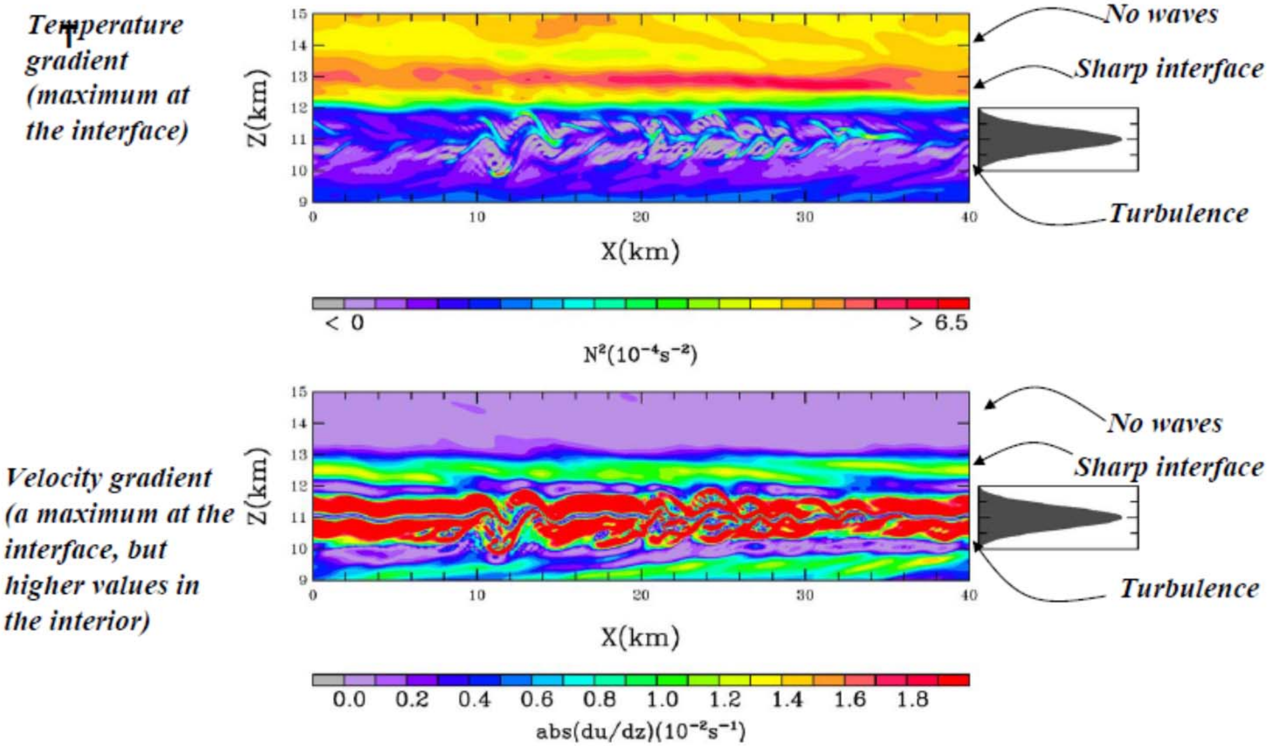
(c) turb /wave mom flux.

Red: Below critical Froude Number
$F_{crit} > F = 2\pi<u>/NL \sim 0.6$
Note N^2 max, no waves

Blue: Above
$F_{crit} < F \sim 2$
Note N^2 no max, with waves

Similar results for mixing layer
U(z) ~Uo H(z)

Instantaneous fields and gradients for moderate Ri and no significant waves

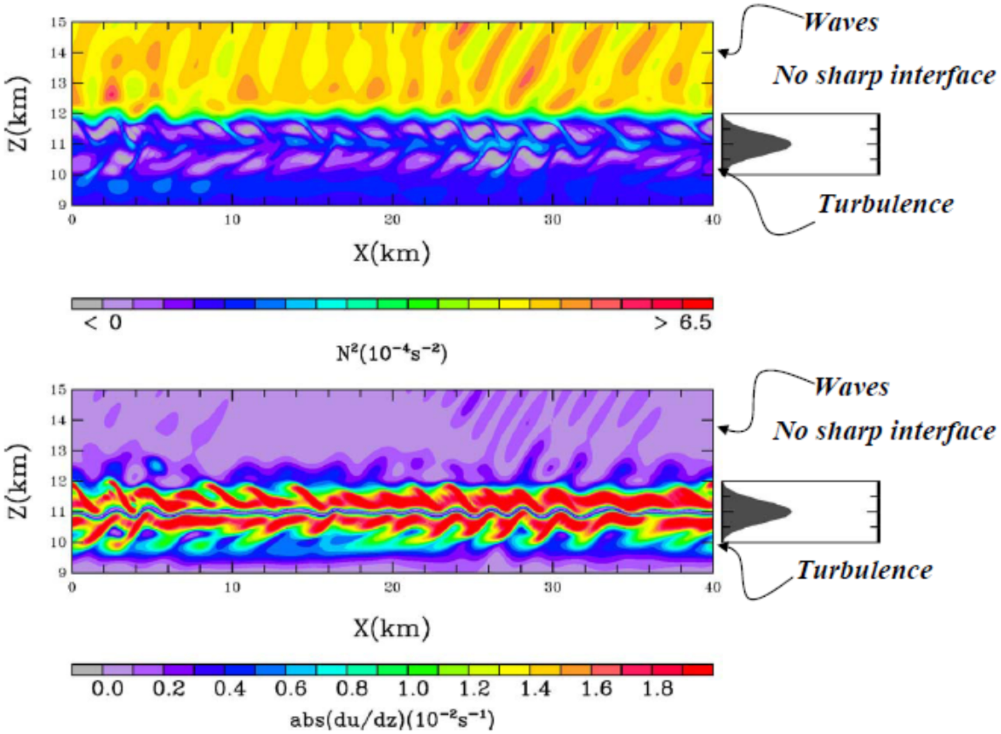


Temperature gradient (maximum at the interface)

Velocity gradient (a maximum at the interface, but higher values in the interior)

Double Inversion layer-like stratus /tropopause?

Fields and gradients with higher Ri with significant wave motion.



Temperature gradient

(No sharp interface i.e. monotonic increase of stability)

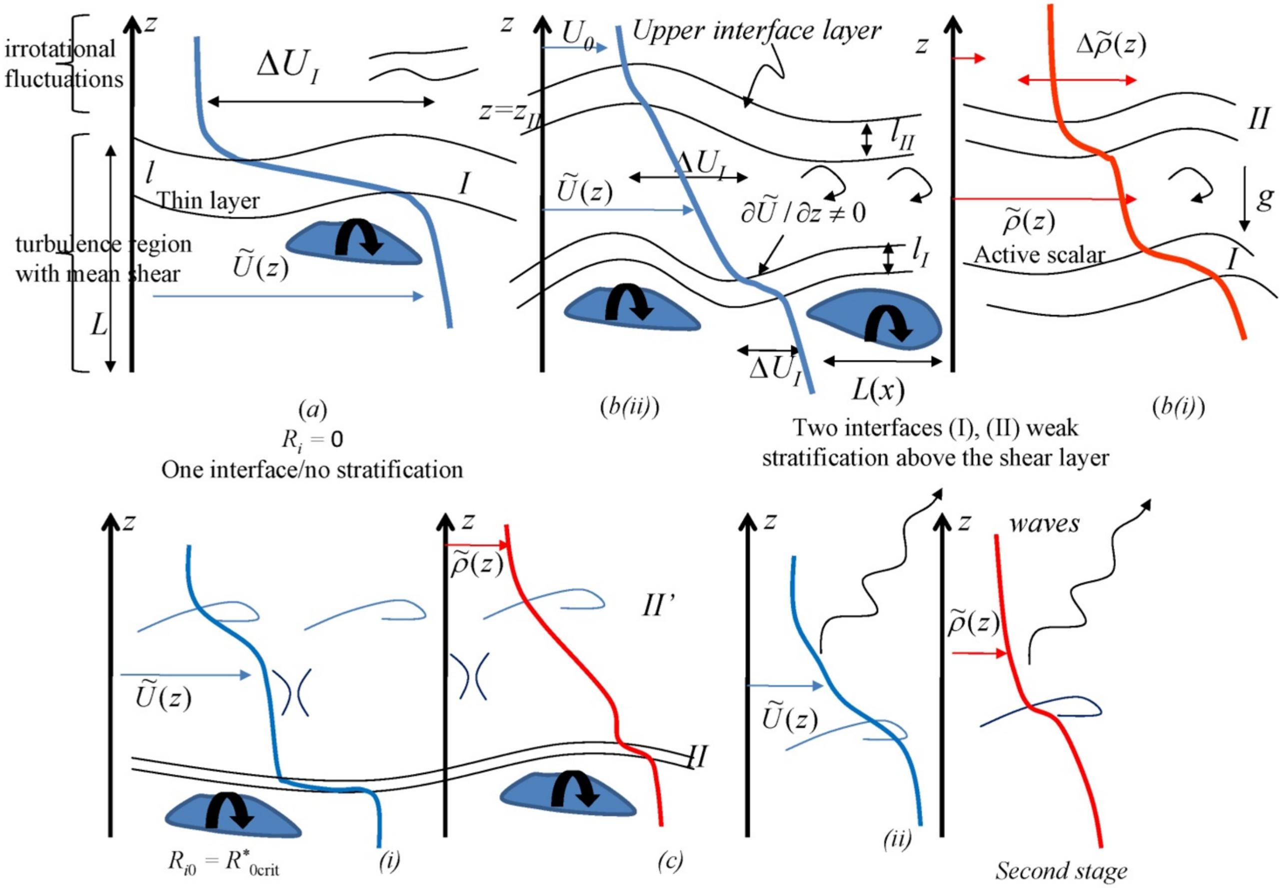
Velocity gradient

(No sharp interface

i.e. monotonic decrease)

Note signifricant

Weak stratification(Ri<Ri’)=0), moderate(Ri’<Ri<Ri*); transition (Ri~Ri*)



(*a*)
$R_i = 0$
One interface/no stratification

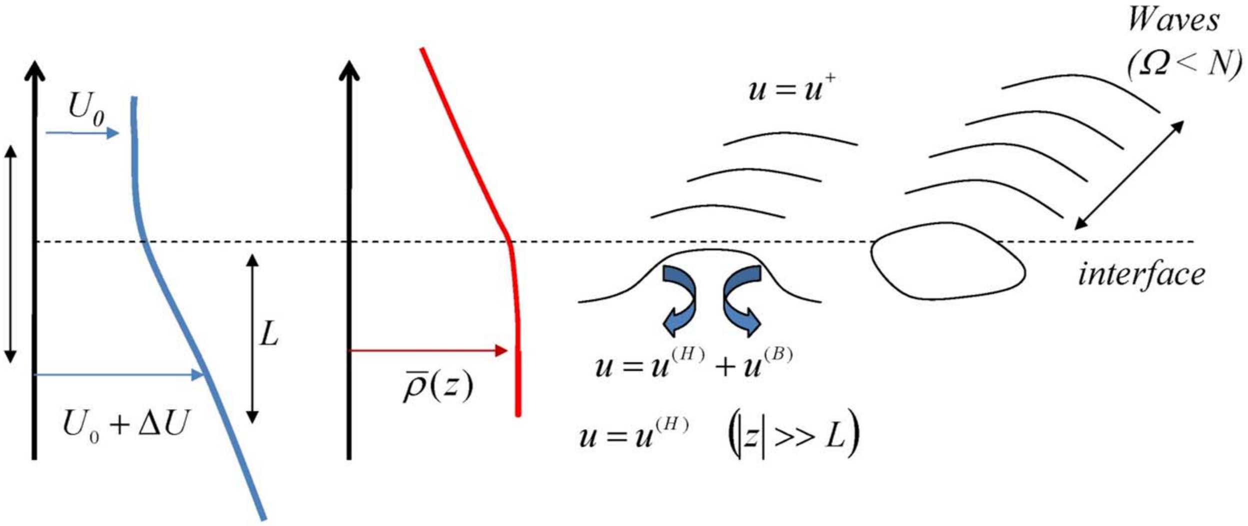
(*b*(*ii*))

Two interfaces (I), (II) weak stratification above the shear layer

(*b*(*i*))

(c) Transition from strong interface to waves –stage (*i*) upper interface (*II*) breaks up
- stage (ii) waves form above I and I thickens.

Mechanisms-blocking z<zi;perturb/waves above zi-travelling at speed Uo.



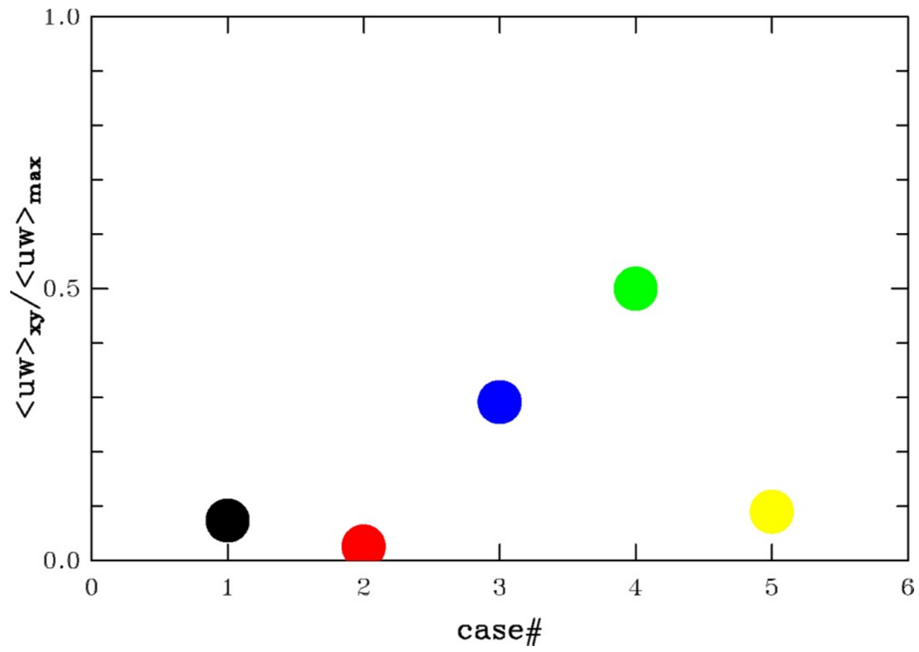
Schematic of RDT calculation for a shear flow below a stably stratified region

WE ASSUME THAT SAME MECHANSMS APPLY IF SHEAR LAYER IS ONE SIDE OF WAKE OR JET.

Shear stress in wave region above shear layer as Ri (>Ri*) increases. Note peak value at certain Ri.

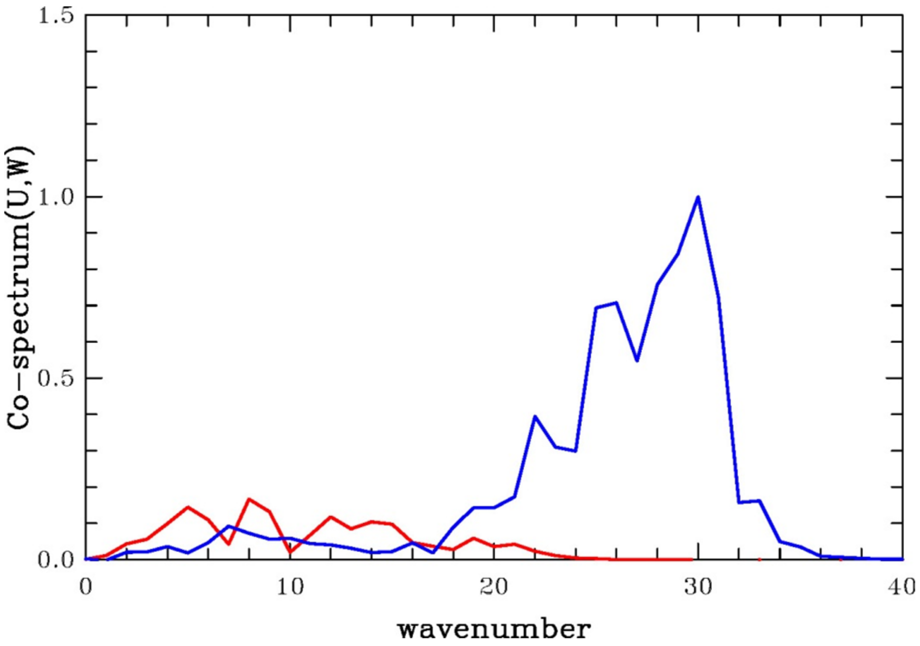
STRESS(Z)/

STRESS(Zi)



Ri --→

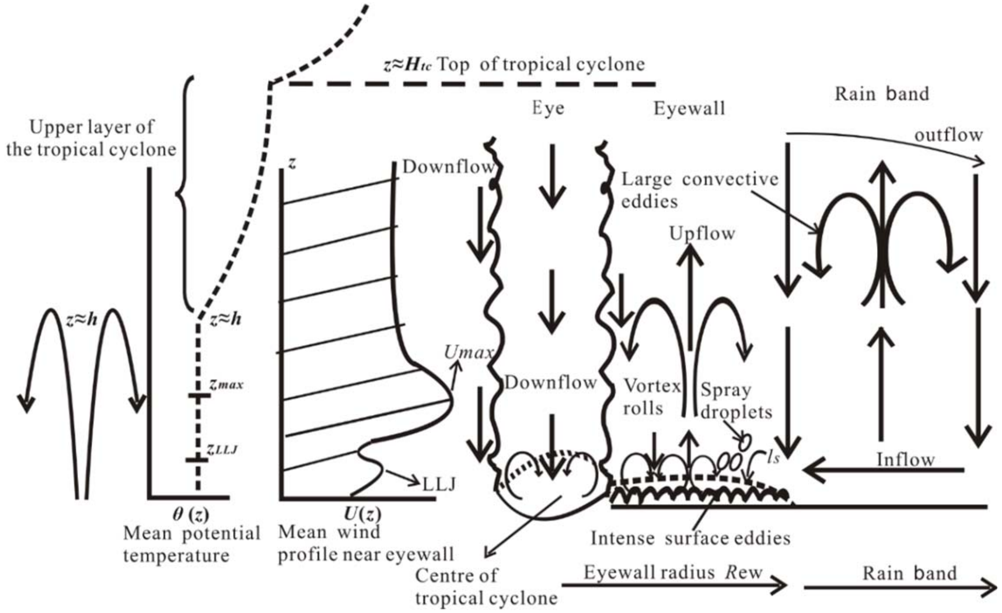
Cospectrum of shear-stress waves for moderate and strong stratification (Z>Zi)

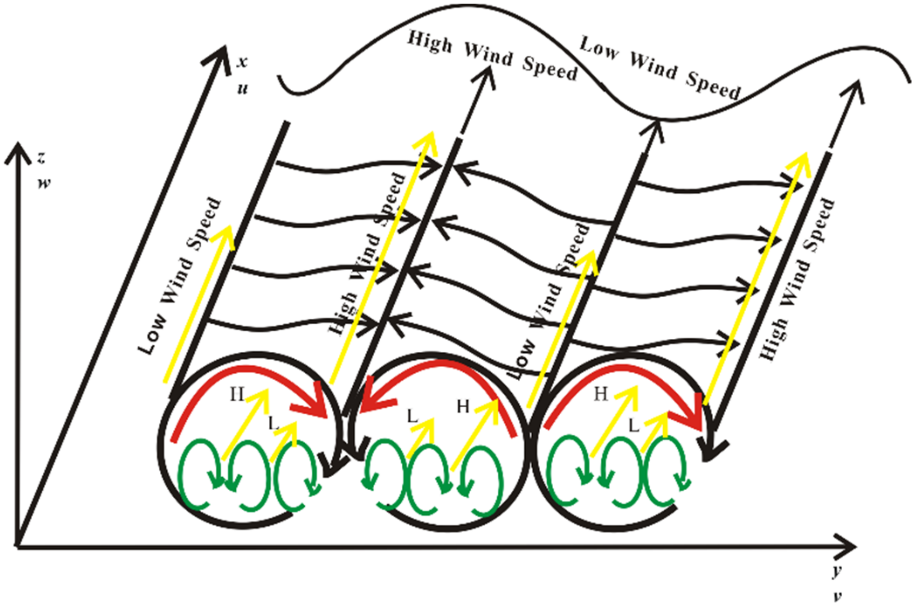


Ri < Ri* -red –no significnt waves; Ri > Ri* (x4) waves on scale of shear layer

Tropical cyclones -Flow and turbulence structure (Lixao, Kareem, Hunt,…BLM 2015)

Levels	Turbulence dynamics
$z = H_{tc}$	Top of the tropical cyclone (typically $H_{tc} \approx$ 5-10 km). Turbulence is cloud-driven convection (but mean temperature profile is slightly stable).
$z_{max} < z < h$	Turbulence is driven by buoyant convection. Its structure is in the form of isolated plumes growing upwards, with smaller plumes feeding into them near their base irrespective of surface processes. The vertically inhomogeneous and anisotropic statistical structure for horizontal and vertical components is determined by the blocking of eddies, either by the sea/land surface if there is no significant shear (outer part of tropical cyclone) or by the mean velocity gradient in the jet (near the eyewall).
$z \approx z_{max}$	In these shear regions with weak convection, roll structures are generated, as occurs in slightly unstable boundary layers over level surfaces (Smedman et al. 2007). The existence of the maxima in the mean velocity profiles tends to separate the eddy structures above and below the levels where there is a maximum in the mean velocity, i.e. low-level jets (LLJs) (Smedman et al. 2004).
$z_{LLJ} < z < z_{max}$	If this intermediate layer exists, the turbulence is largely driven by the mean wind shear $\mathrm{d}U/\mathrm{d}z$.
$z = z_{LLJ}$	In some situations, the mean azimuthal velocity U has a local maximum at $z = z_{LLJ}$ associated with a low-level jet (LLJ).

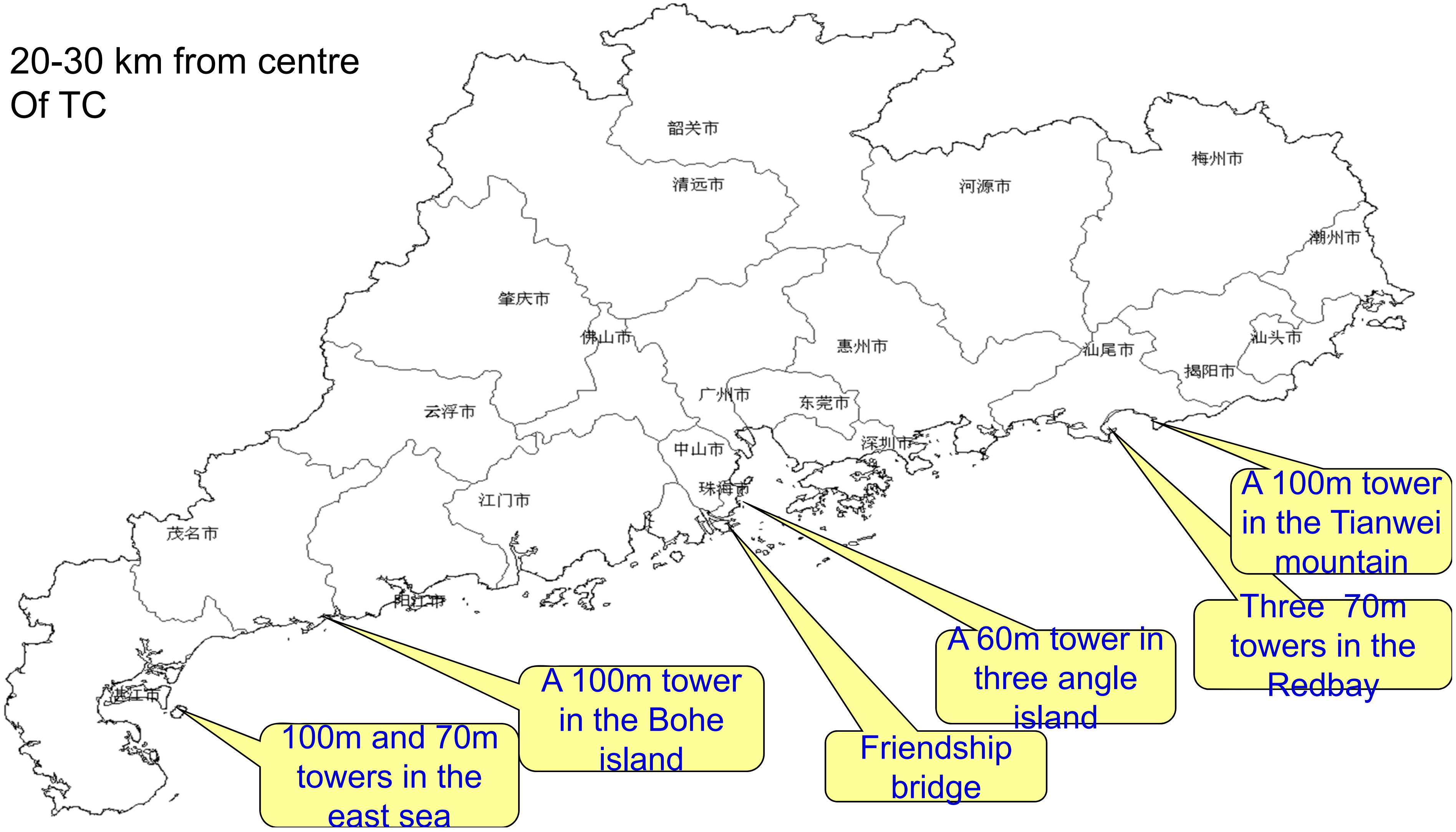




COASTLINE TYPHOON OBSERVATION NETWORK (CTON)

- The distribution of wind observation towers

20-30 km from centre
Of TC



A 100m tower in the Tianwei mountain

Three 70m towers in the Redbay

A 60m tower in three angle island

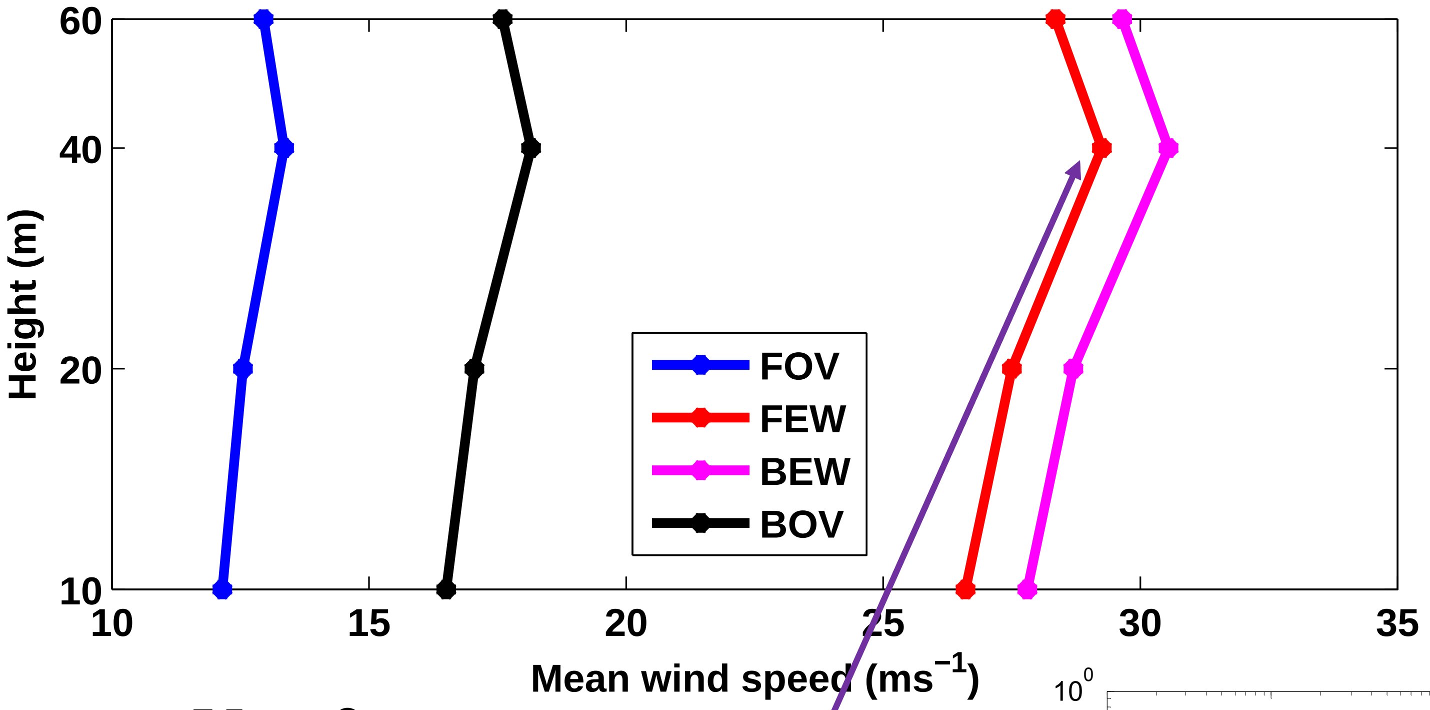
Friendship bridge

A 100m tower in the Bohe island

100m and 70m towers in the east sea

FIELD MEASURED PROFILES &TURBULENCE SPECTRA

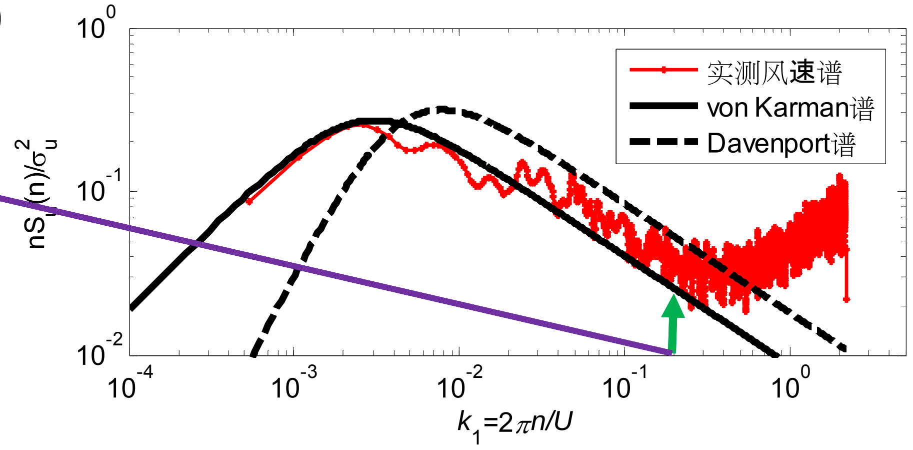
-> Eddy scale ~ upper surface layer depth ~40m



Turbulence and spray from eyewall region with scales less than about 30m.=height of Velocity maximum.

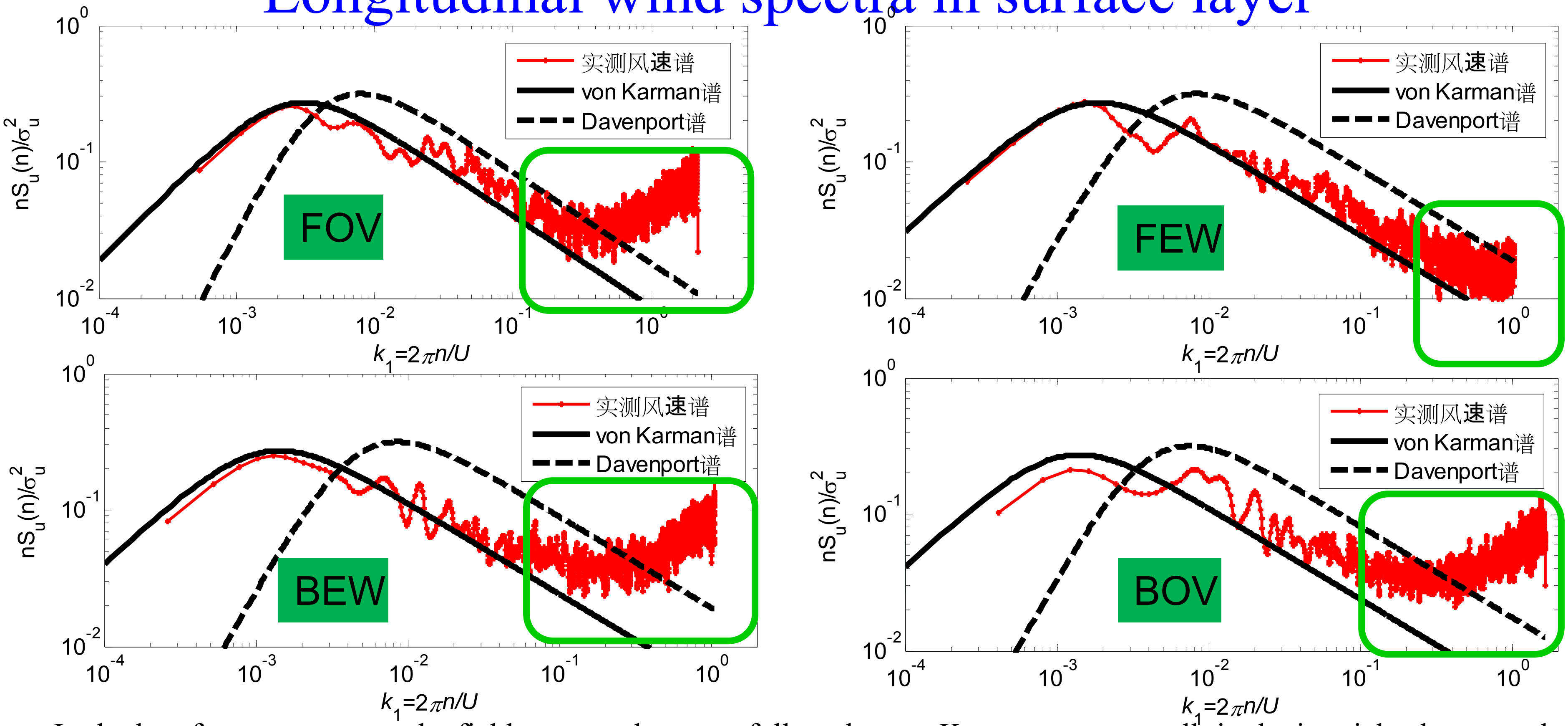
$$\lambda = \frac{U}{n} = \frac{2\pi}{k_1} \qquad k_1 \approx 0.2$$

$$\lambda = \frac{U}{n} = \frac{2\pi}{k_1} \approx \frac{2\pi}{0.2} = 31.42$$



FIELD MEASURED TURBULENCE SPECTRA in forward/backward directions

Longitudinal wind spectra in surface layer



- In the low frequency range, the field measured spectra follow the von Karman spectra well; in the inertial sub-range, the field measured spectra were located in the range between von Karman spectra and Davenport spectra
- In the high frequency range, additional energy were detected.
- Near the surface in the boundary layer of tropical cyclones, dynamically active and passive near-surface process (e.g. convective motions driven by the relative movement of the spray droplets, and by the evaporation of spray droplets) and top-down convective and sheared eddies add extra energy to the spectra of the boundary-layer turbulence.

Applications

- Dynamics/thermodynamics of wave/spray production , ->thermal effects ->

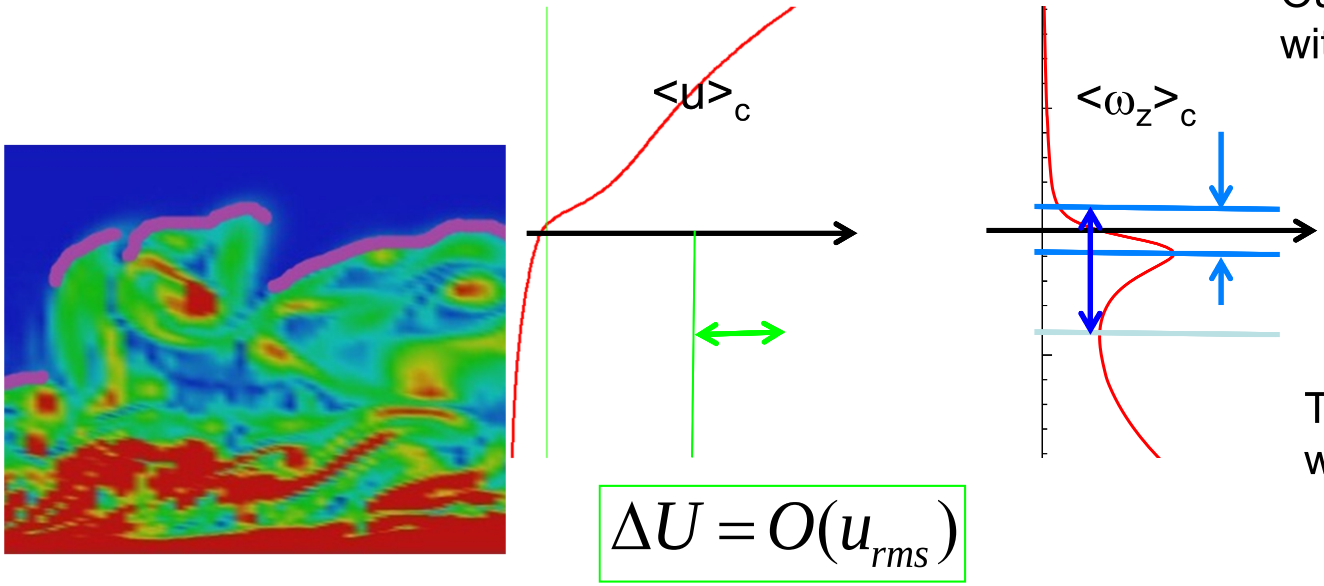
Significant buoyancy forces affecting turbulence .

- Wind loading on structures affected by TC.

-different to neutral boundary layers.

Summary of the second part

- We studied the properties of the T/NT interface of TBL by using DNS (Re_θ=500-2200).
  - Scales



$$\Delta U = O(u_{rms})$$

Outer boundary (superlayer) with thickness

$$l_S = O(\eta)$$

A inertial-viscous double structure

Turbulent sublayer with thickness

$$l_I = O(\lambda)$$

  - De-correlation of the velocity fluctuations across the interface, which is consistent with blocking mechanism by Hunt & Durbin 1999

Weak Stratification

Consider the first order linear analysis of Carruthers & Hunt (1986)

$$\left\{ \frac{\partial^2}{\partial t^2} \nabla^2 + N_o^2 \nabla_H^2 \right\} w(\mathrm{x}, t) = 0$$

$$\widetilde{w}(z=0) = \hat{w}(z) \exp[i(k_1 x + k_2 y - \omega t)]$$

$$\left\{ \frac{d^2}{dz^2} - k_{12}^2 \left(1 - \frac{N_o^2}{\omega^2} \right) \right\} \hat{w} = 0 \quad (2.1c)$$

From the solution to (2.1c), for $\frac{N_o}{\omega} < 1$ or $Ri = \left(\frac{N_o L}{\Delta U_I} \right)^2 < Ri^* \sim 1$

the fluctuating velocity and vorticity decay exponentially with distance above the interface. i.e. $\widetilde{w}(z,k) = \widetilde{w}(z=0) \exp(-k_{12} \lambda z)$

where $k_{12}^2 \lambda^2 = k_{12}^2 \left(1 - \frac{N_o^2}{\omega^2} \right) = k_{12}^2 (1 - Ri)$

and horizontal-vorticity $\omega_y \sim \frac{\widetilde{w}(z=0)}{L} Ri \exp(-k_{12} \lambda z)$ Increases with Ri

Vertical decay distance $L^+ = \frac{1}{(k_{12}\lambda)^{1/2}}$ increases with Ri , since

$$L^+ = \frac{L}{\sqrt{1-Ri}}$$ for Ri < 1

(i) Velocity and vorticity fluctuations move with the relative velocity ΔU.

(ii) The straining by the gradient of the mean drift velocity $\left(\frac{dU_d}{dz}\right) \left(\sim \frac{w^+}{L^+}\right)$

of the velocity fluctuations at the interface

=> (iii) amplifies the vorticity ω until it is of the order of the strain rate $\frac{w^+}{L^+}$

Note Ri > Ri' (cf turbulence below water waves)

$$L_e^+ \sim \frac{w^+}{N} < L^+$$

Note Ri > Ri' where $\frac{L^2}{1-Ri'} \sim \left(\frac{w^+}{N_o}\right)^2$ => $Ri' \sim \left(\frac{w^+}{\Delta U_I}\right)^2$

DOUBLE INVERSION LAYER STRUCTURE FORMS –INVERSIONS AT Z_I AND Z_{II}., CORE LIES BETWEEN LOWER & UPPER INVERSION LAYER

Jump in velocity across the core is $\Delta U_c \sim \frac{N_o w^+}{N_o} \sim w^+$

The total change ΔU in mean velocity across 2 interfaces + core is

$$\Delta U = \Delta U_I + \Delta U_c + \Delta U_{II} \sim \Delta U_I + \Delta U_{II}$$

=> $$\Delta U_I = \Delta U_{II} \sim \frac{\Delta U}{2} \quad (2.7c)$$

from (2.7c) that Ri' = $(N_o L/\Delta U)^2 >> ¼$.

Moderate to Strong Stratification
With significant wave motion z>0.

$$\mathbf{u} = \mathbf{u}^{(H)} = (\hat{u}^{(H)}, \hat{w}^{(H)}) \exp[i(k_1(x - \Delta U_I t) + k_2 y + \chi_3 z)]$$

where $\chi_3 = k_3 - k_1\beta$ and $\beta = \alpha t$ Note χ_3 Increases with shear

For z < 0 since $\nabla^2 \phi = 0$ $\tilde{w} = \hat{w}^{(H)}\left(\exp[i\chi_3 z] + A\exp[k_{12} z]\right)$ $k_{12} = \sqrt{k_1^2 + k_2^2}$

Continuity => $\hat{u}^{(H)} = -\chi_3 \hat{w}^{(H)} / k_1$

For z > 0 the modal equation is $\dfrac{d^2\hat{w}}{dz^2} + \left(\dfrac{N_o^2}{\omega^2} - 1\right) k_{12}^2 \hat{w} = 0$

Let $\mu = \sqrt{\dfrac{N_o^2}{\omega^2} - 1}$ where $\dfrac{\Delta U_I}{L} \sim \omega < N_o$

$\hat{w} = \hat{w}^{(H)} C \exp[-i\mu k_{12} z]$ For $k_1 > 0$ and by continuity $\hat{u} = \hat{w}^{(H)} C\mu \dfrac{k_{12}}{k_1} \exp[-i\mu k_{12} z]$

For z > 0, $\tau = \frac{1}{2}\left(\overline{\tilde{u}\tilde{w}^*} + \overline{\tilde{u}^*\tilde{w}}\right) = \overline{\left|\hat{w}^{(H)}\hat{w}^{(H)^*}\right|}\left|C\right|^2 \mu \frac{k_{12}}{k_1} \propto \left(\frac{\Delta U_I}{N_o L}\right)\overline{w^{(H)2}}$ for $\frac{\Delta U_I}{N_o L} << 1$

$\propto \mu$ when $\mu << 1$

The maximum value of $\frac{\tau}{w^{(H)^2}} \sim 1$ when $\mu \approx 1$

and $Ri = \left(\frac{N_o L}{\Delta U_I}\right)^2 \approx 2$ and decreases as Ri increases

$$\frac{\overline{\left|\hat{w}\right|^2}}{\overline{w^{(H)^2}}}(z > 0) = \left|C\right|^2 = \frac{(k / k_{12})^2}{1 + \mu^2}$$

Note the ratio $\frac{|\tau|}{\overline{w^2}} \sim \mu$

Note in shear flow $\frac{|\tau|}{\overline{w^2}}$ is of order unity

The mean stress for a single mode is $\tau = -\frac{1}{2}\left[\overline{uw^*} + \overline{u^* w}\right] = -\left|\hat{w}^{(H)}\right|^2 (t)\frac{\chi_3}{k_1}$

$$\sim \left|\hat{w}^{(H)}\right|^2 \beta \quad if \quad \beta >> 1$$

Near the interface (from Lee & Hunt 1989) the turbulence is distorted by the eddies being blocked, ie

$\widetilde{w} = \hat{w}^{(H)} + \nabla\phi$ where $\nabla^2\phi = 0$

$$\widetilde{w} = \widetilde{w}^{(H)} \exp\left(i\left(k_1 x + k_2 y\right)\right)\left[\exp(i\chi_3 z) + A\exp(k_{12} z)\right]$$

By continuity $\widetilde{u} = \hat{w}^{(H)} \exp\left(i\left(k_1 x + k_2 y\right)\right) \times \left[-\frac{\chi_3}{k_1}\exp(i\chi_3 z) - iA\frac{k_{12}}{k_1}\exp(k_{12} z)\right]$

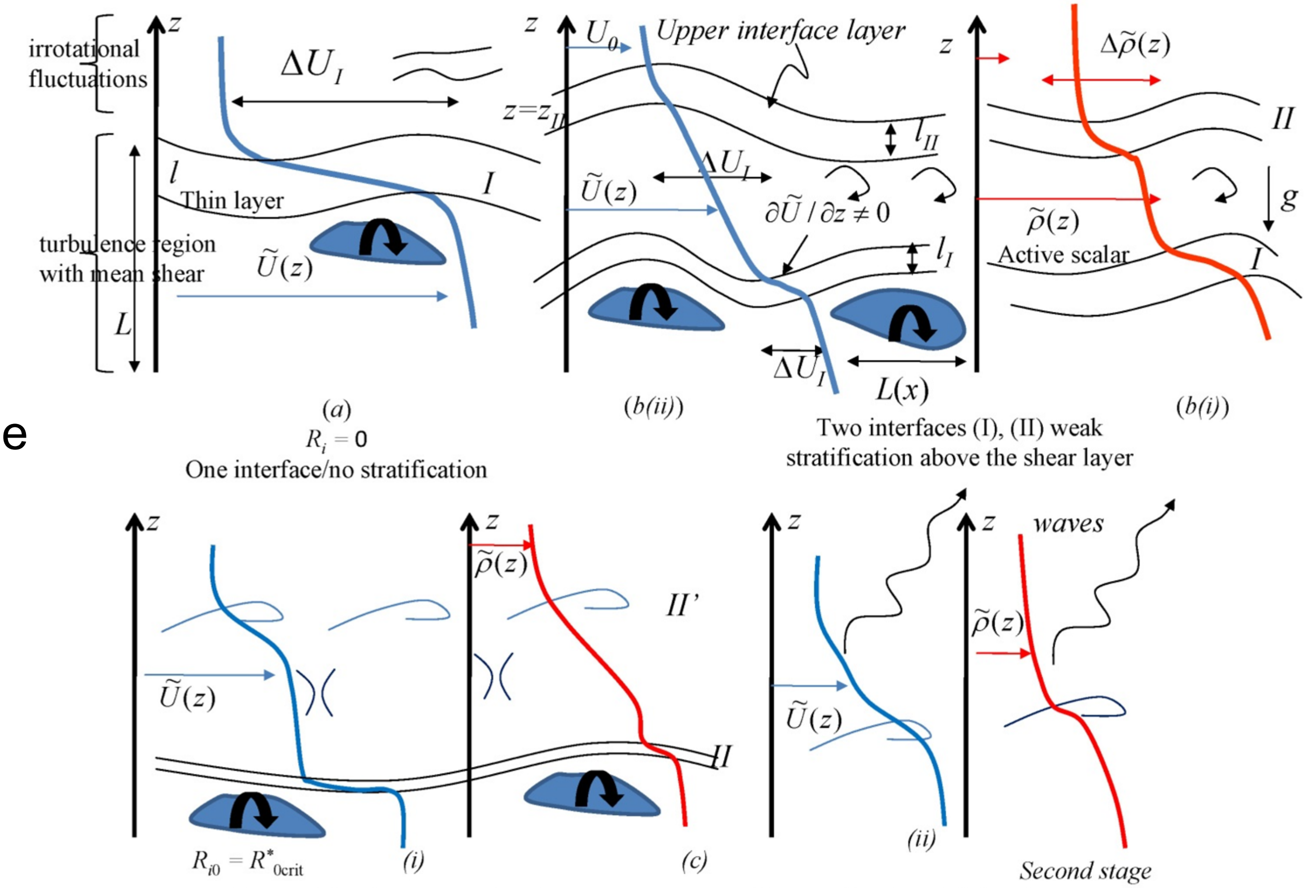
The vertical velocity at the interface is given by

$$\left|\widetilde{w}\right|^2 (z = 0) = \left|\hat{w}^{(H)}\right|^2 \left(k_{12}^2 + \chi_3^2\right) / \left(k_{12}^2\left(1 + \mu^2\right)\right)$$

Weak stratification(Ri<Ri')=0), moderate(Ri'<Ri<Ri*); transition (Ri~Ri*)

Randell
Et al 2007
Double
Tropopause
 Trapped
pollution

Stratus
Layer
Dynamics
(add
to thermo
Dyn)



(a)
$R_i = 0$
One interface/no stratification

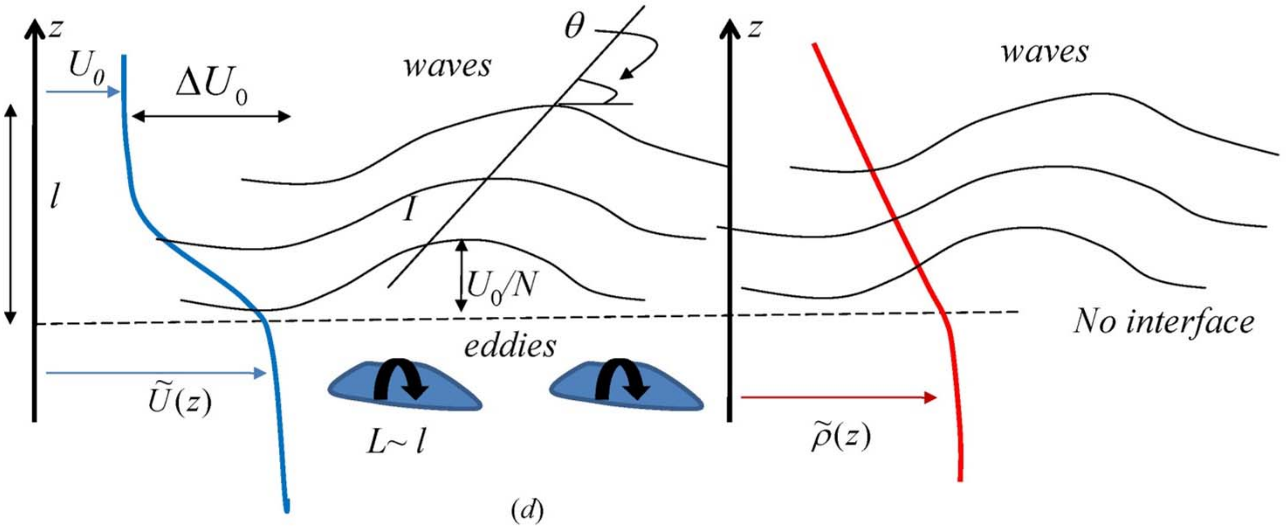
(b(ii))

Two interfaces (I), (II) weak stratification above the shear layer

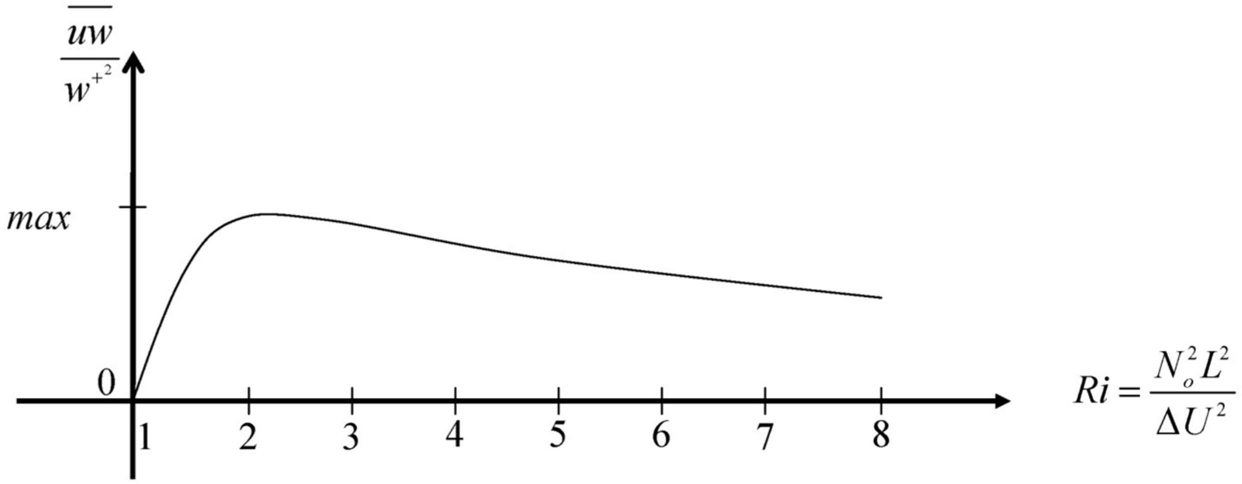
(b(i))

(c) Transition from strong interface to waves –stage (*i*) upper interface (*II*) breaks up
- stage (ii) waves form above I and I thickens.

Eddies near shear interface
Ri> Ri*-smooth turb-wave transition

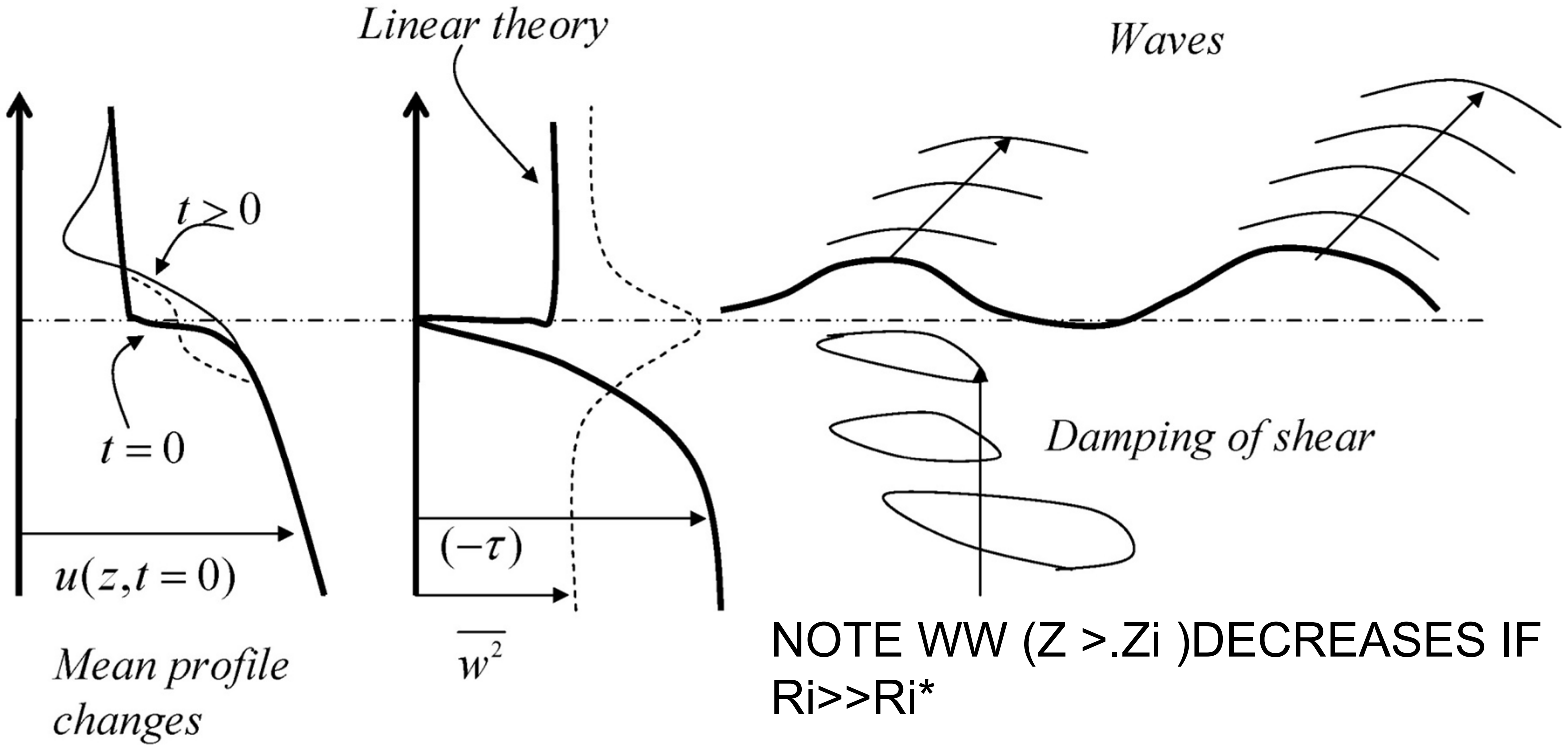


Wave shear stress-normalised on turb in shear layer-RDT model $\sim\mu/(1+\mu^2)$;μ=sqrt(Ri/Ri*-1)



Variation of the normalized wave Reynolds stress with Ri for Ri > Ri = 1*

Profiles of vertical turbulence and shear stress when waves are generated in the upper region

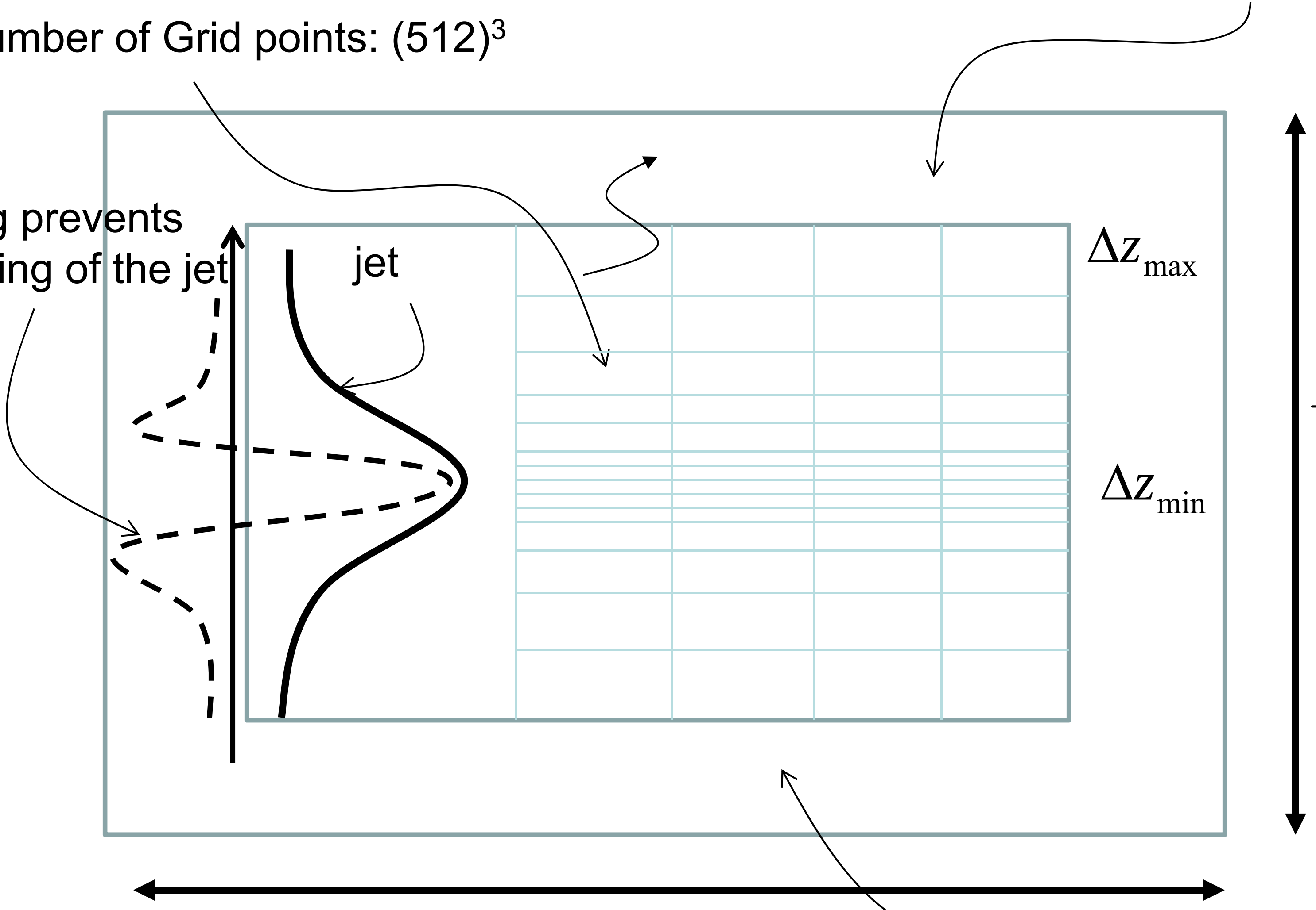


NOTE WW (Z >.Zi)DECREASES IF Ri>>Ri*

Showing the profiles of vertical turbulence and shear stress when waves are generated in the upper regions i.e. $Ri = N_o L/\Delta U$

NOTE Ri >Ri* ; profiles change with non-linear effects –see DNS results

3-D Navier-Stokes Numerical Solver



Parallel computations

Number of Grid points: $(512)^3$

Absorbing boundary conditions

Forcing prevents spreading of the jet

$$\frac{\Delta z_{\max}}{\Delta z_{\min}} = 20$$

$$\frac{\Delta x}{L} = \frac{1}{512}$$

Re = 1000

Absorbing boundary condition

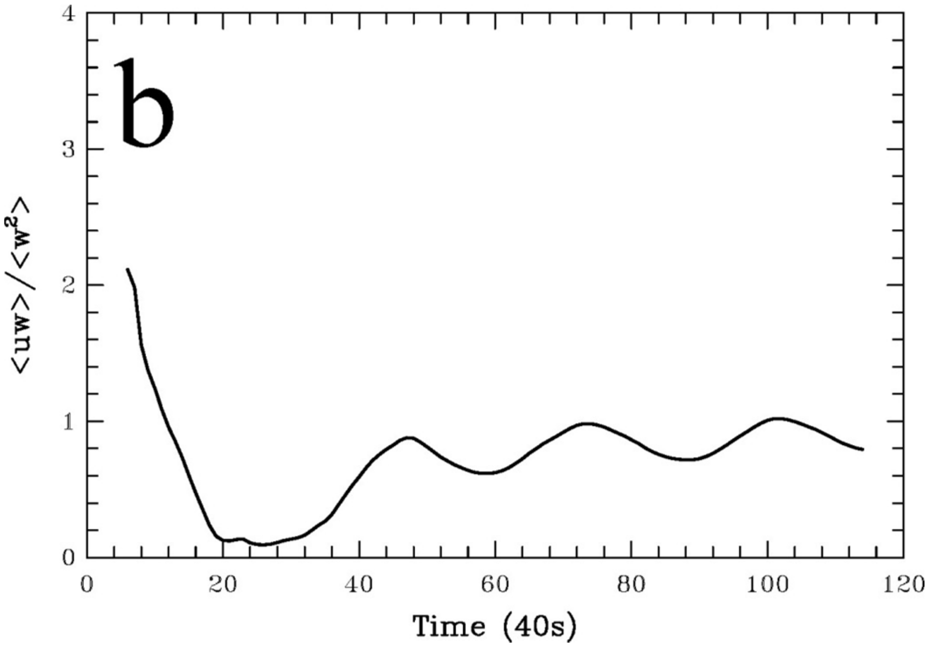
Numerical simulation of shear stress in wave region –normalised on turb in shear region.

Forcing of jet to

Ensure steady

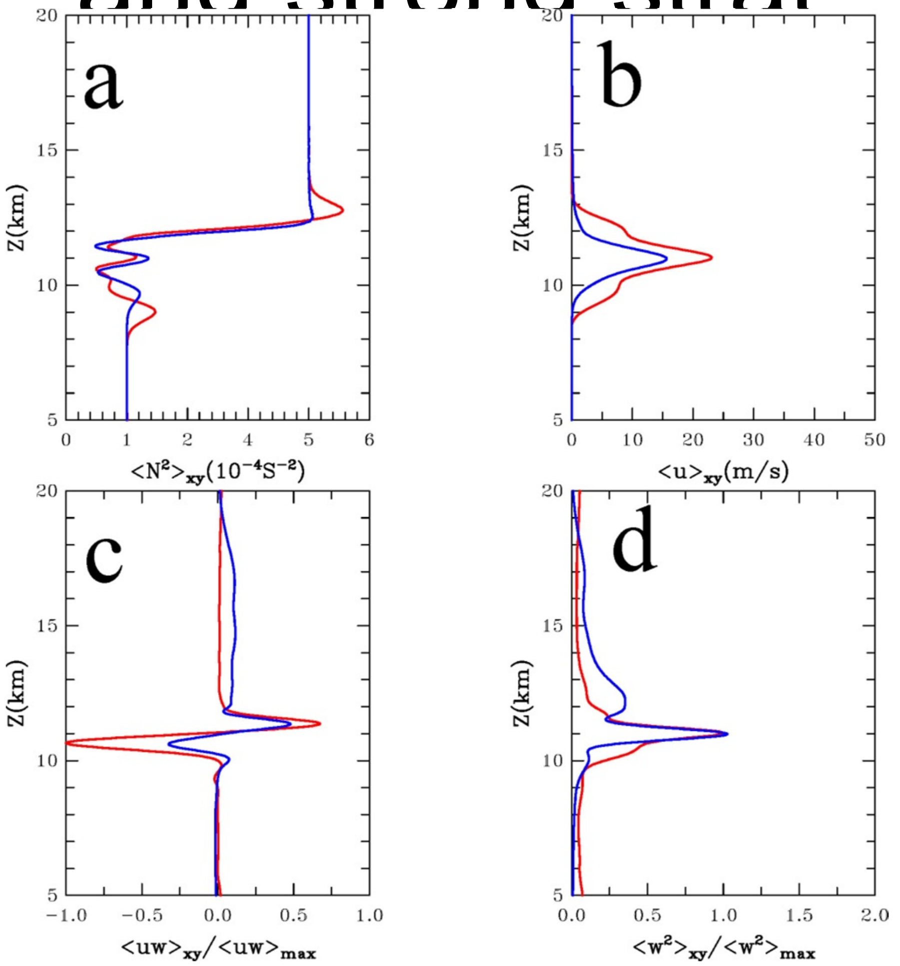
Conditions

$$\sim -\nu \frac{d^2U}{dz^2}$$



STRESS AVERAGED OVER HORIZONTAL PLANE

Num Sim. Vertical Profiles. In quasi equilibrium for moderate and strong strat



Ri < Ri*
(MODERATE)-RED

Ri>Ri*

(STRONG-WAVES)

BLUE

A – BUOYANCY FREQ

B- MEAN VEL.PROFILE

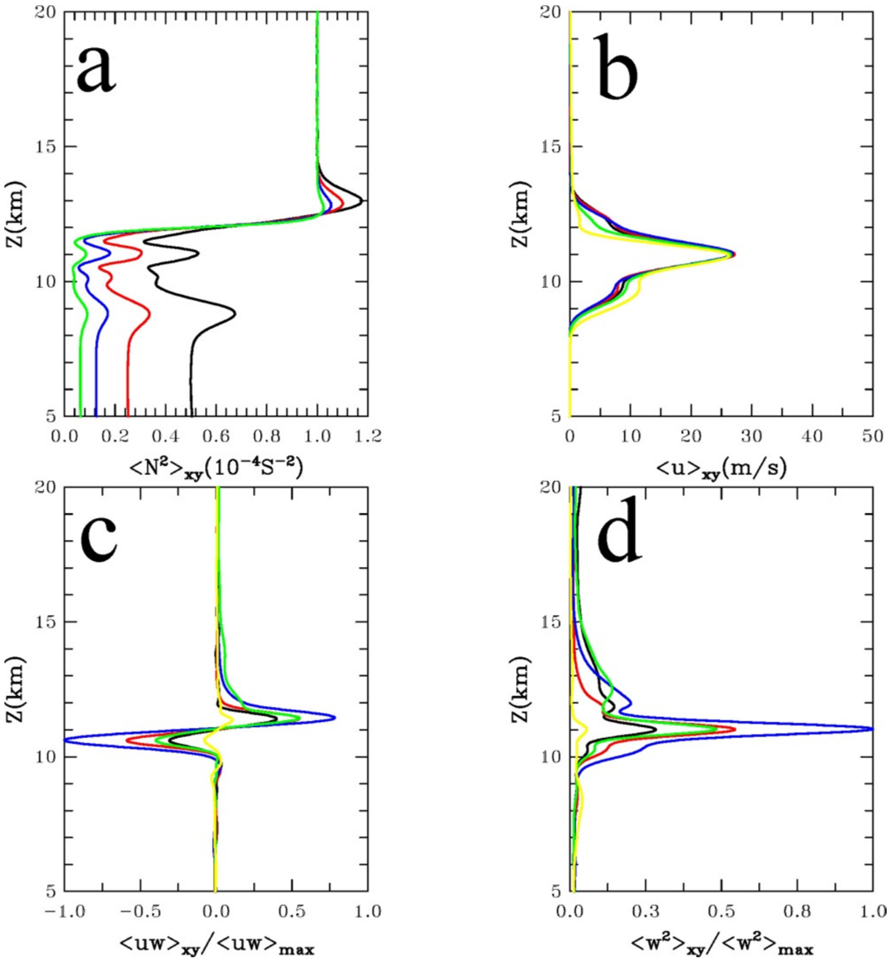
C- SHEAR STRESS

D-VERTICAL

TURB

Profiles in wave region for increasing Ri (>Ri*)

A . BUOYANCY
 FREQUENCY-
NOTE PEAK
 DECREASES
WITH Ri



MEAN VEL
PROFILES –
LESS KINK AS
Ri INCREASES

C,D –LARGE
VARIATIONS IN

SHEAR STRESS
AND VERTICAL
TURB WITH Ri.

Filtering of turbulence by stratification in wave field.

ω WavEs

Turb Sh’r

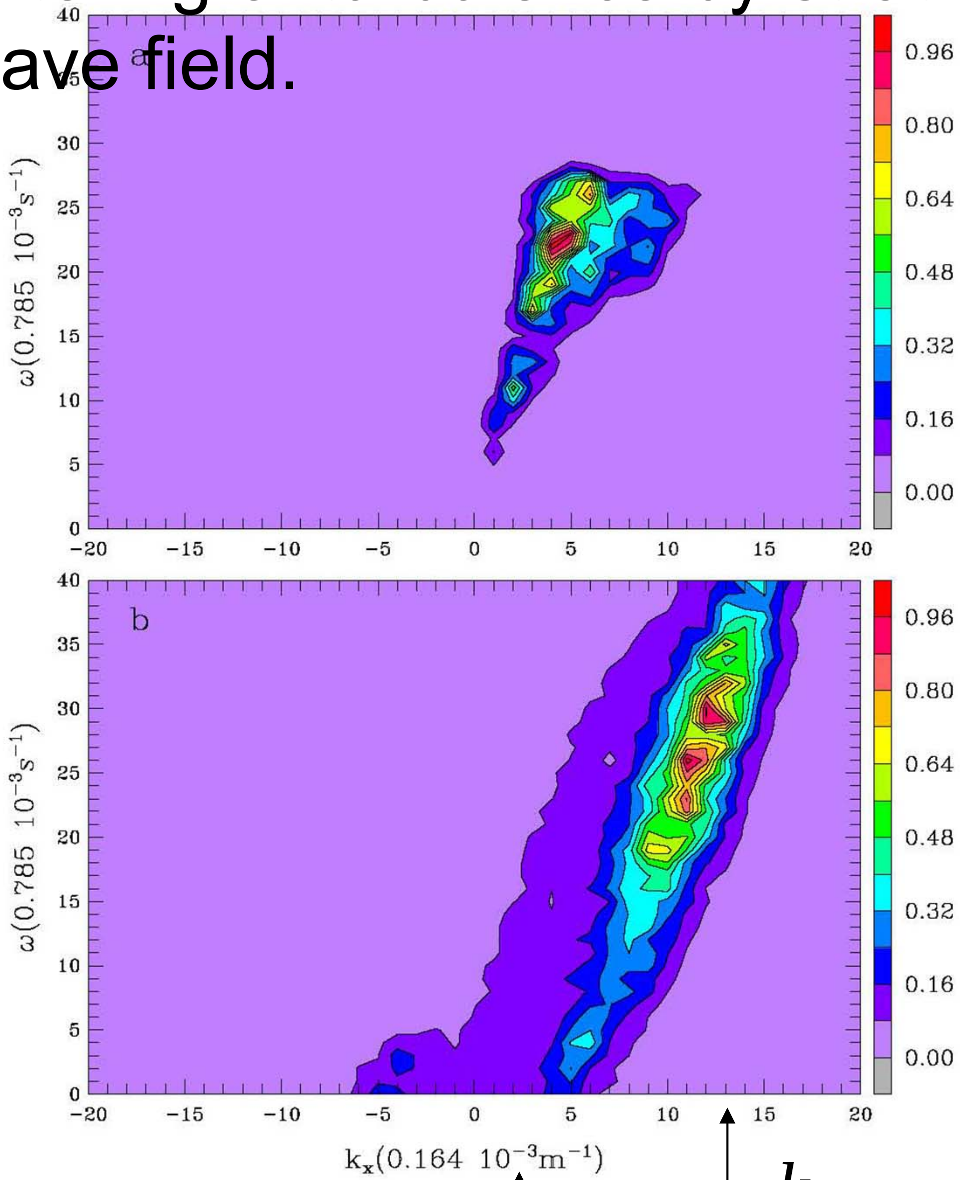


Fig. 8 Normalized co-spectra of (U,W), averaged over the spanwise wave numbers at z=24 km (a), and at the upper flank of the jet (b)

ω_{wave}

ω_{turb}

k_{turb}

k_{wave}

k

Conclusions about shear-layer and stable –stratification interactions

- Turbulent layer with weak shear +stable strat (Z>Zi) ->sharp interface and waves

  (can transport 20% of dissip energy)
- Turb shear layer plus weak/moderate stable strat (Ri <Ri*) leads sharp interface (or two) with weak waves -> stratus blcloud/-> NEEDS MORE
- RESEARCH AND VERIFCN IN CLOSURE MODELS
- Turb shear layer plus strong strat (Ri>Ri*)

Leads to waves with shear stress (1/5-1/4)

Of peak stress-> significant momentum

Applications

- Propagation of momentum below Ocean mixed layer – big errors in current models for equatorial regions with no Coriolis.

- Urban surface SBL, Growing Convective BL in early morning , Ri < Ri*-> 2layer structure (Upper layer may be the residual of previous day cbl)-> elevated pollution layers with low pollution at surface
- Stratus layers above nbl and cbl-when <Ri'Ri <Ri*
- note these fluid flow mechanisms reinforce other processes sea breeze, urban bl layers, avalanche processes etc

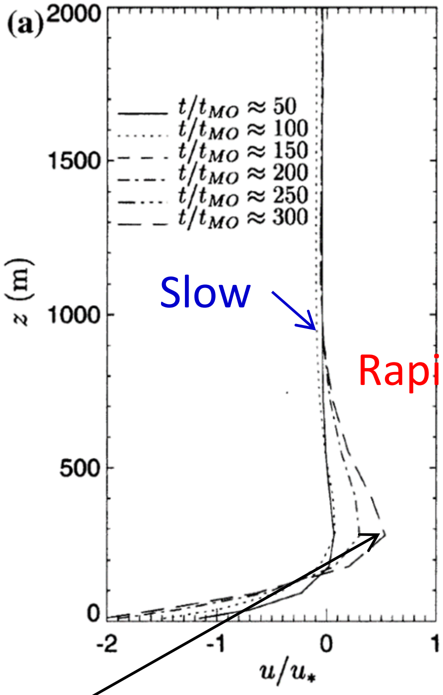
.

Slow/Rapid Change in Buoyant Heat Transfer in Turbulent Boundary Layers [Owinoh et al. 2005]

- **Slow:** $T_D > T_L$

(Distortion time) (Eddy time scale)

  - e.g. High latitude boundary layer
- **Fast:** $T_D < T_L$
  - e.g. Low latitude BL or Sudden change in indoor flow



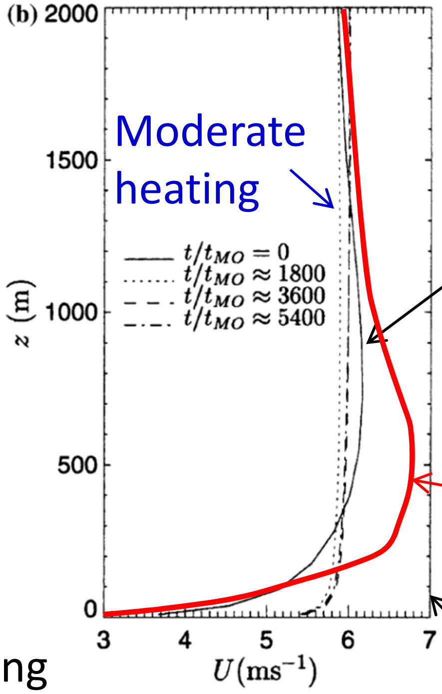
Slow

Rapid Cooling

Wind jet

<- 'the land Beneath the Wind' 17th Century !

Typical tropical evening with stagnant air below jet



Moderate heating

Initial profile

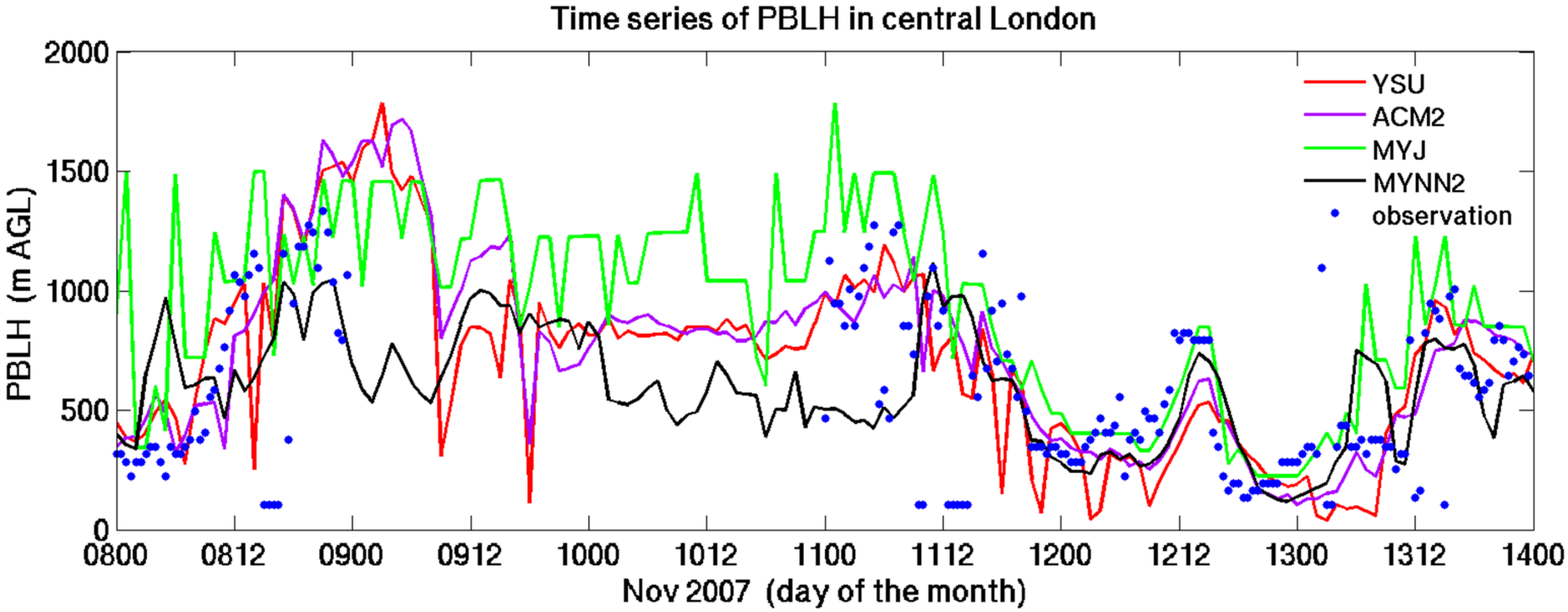
(Jet) Strong rapid Heating

Typical sea breeze

- Standard boundary layer models are wrong for fast heating cooling

Owinoh, A.Z. (2005), "Effects of changing surface heat flux on atmospheric boundary-layer flow over flat terrain", *BL Met* **116**, 331-361

- Mixing height h - reflects changing abl structure ; critical for dispersion and concentration. (wrf modelling; BT Tower



Essential concept of adms, aermod is to represent abl parameters as functions of z/ h and h/L $_{MO}$; Xie bo et al 2013 (cerc, hk, reading) J Geo Res (atm) 118